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Fire's Effects on Wildlife Habitat—Symposium Proceedings

Missoula, Montana, March 21, 1984

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FOREWORD

The symposium, "Fire's Effects on Wildlife Habitat," represents one of the closing ceremonies of the Fire Effects and Use Research and Development Program, conducted by the Intermountain Research Station from 1979 to 1984. One of the R&D program's most important goals had been to study the long-and short-term effects of fire on plant communities. We sought to thus enhance our understanding of fire's effects on vegetation, so fundamental to managing forests and rangelands for their many resources.

Judicious use of fire probably benefits wildlife more than any other resource. For eons, the wildlands and wildlife of the Northern Rockies and Intermountain West have been shaped by fire. Therefore no management tool is more appropriate than fire for manipulating wildlife habitat. Fire, unfortunately, produces various effects on wildlife habitat, depending on fuels, weather, and the site. Before we can use fire with great confidence, we must be able to evaluate these factors and predict the result.

Settlement by Europeans drastically curtailed fire's influence on wildlife habitat. Fire control, grazing, and settlements have all markedly reduced the number and size of fires in the American West. George Gruell's comparisons of early and recent photos illustrate the magnitude of changes in vegetation over the past century. The photos document that the early stages of plant succession, perhaps the optimum in wildlife habitat, were gradually replaced by even larger and more abundant conifers that provide comparatively poorer wildlife habitat. We have come to recognize that prescribed fire is the most effective and most economically feasible tool for rejuvenating vast expanses of deteriorating wildlife habitat.

Land managers have slowly and carefully begun to use prescribed fire to rejuvenate wildlife habitat. Nevertheless, they desperately need sound knowledge of fire's effects. The kind of fire that results and the influence of the season in which the burn is done are particularly important. The purpose of this symposium is to assemble some of this knowledge and make it available to others. We trust that the information herein will ultimately benefit wildlife and that the work reported will stimulate additional investigations. The future of wildlife depends upon intelligent maintenance of its habitat and in this endeavor fire will remain an important tool.

James E. Lotan and James K. Brown
Symposium Co-chairmen

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Fire's Effects on Wildlife Habitat— Symposium Proceedings

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WILDLIFE AND FIRE RESEARCH: PAST, PRESENT, AND FUTURE

E. V. Komarek

INTRODUCTION

A keynote speaker has a unique advantage. Somewhat like a historian, he can look backward in time and also discuss the present. Unlike the historian, he may also point to the future. A keynote speaker also can ramble more or less all over the countryside. He doesn't have to have too much quantitative data and must be rather holistic in his approach.

According to the dictionary, a keynote address is supposed to present the essential issues of interest to the assembly. To fulfill that requirement, I will spend most of my time for what I see as the problems for the future, pointing out areas where research needs to be done--or continued and expanded--on the relationship of fire and wildfire.

THE PAST

Game management began on an empirical basis in the South at least by the early 1800's. At that time, scientific wildlife management began with the Cooperative Quail Study Investigation in the 1920's. Although the use of fire to attract game animals has been a practice well known to early peoples, including American Indians and our pioneer ancestors, this folk knowledge was overlooked in the attempt to preserve our Southeastern forests in the late 1920's and early 1930's.

The passage of the Clarke-McNary Act (1924), sponsored by the American Forestry Association, provided for Federal matching funds from the U.S. Forest Service and the development of State forest agencies in the South. These funds were earmarked only for fire fighting, not for fire prevention.

Bonninghausen pointed out:

> "in order to carry our the cooperative fire control agreements which the Florida Forest Service entered in to with private land owners at that time, it was necessary to stipulate the exclusion of fire, or funds would not be made available and the Florida Forest Service would be subject to criticism" (Bonninghausen 1962).

Thus, southern silviculture in practice became largely fire control. Along with the stimulus of Federal funds came the philosophy that all that was necessary for the original splendid forest to return was to prevent fire, exclude hogs, and leave ample seed trees; nature herself would restore longleaf pine to its primeval state.

During this period, however, there were roughly 1 million acres (40 500 ha) of southeastern pine and agricultural lands throughout the Coastal Plain devoted to quail hunting and winter recreational activities. These plantations had been burned regularly, mainly on an annual basis, for well over 50 years. Many of these plantations, ranging from 5,000 to 20,000 acres (2 000 to 8 000 ha), also had winter residences upon them; owners and their friends often came South for the 3 winter months. The area around Thomasville, GA, and Tallahassee, FL became the center for some of the earliest hunting. In addition to hunting owned land, these plantation owners also leased adjacent lands for hunting; within the lease was always a stipulation that after the end of the hunting season each year, usually on the last day of February, the properties would be burned in order to maintain the quail population.

With the Clarke-McNary Act, however, intensive efforts were made to stop all burning in the Coastal Plain of the Deep South. Instead of being blamed on timbermen, forest destruction was blamed on fire. The South was then subjected to a "crusade" by the American Forestry Association and the participating southern State forest services (Florida, Georgia, and Mississippi). It was called the Southern Forestry Education Project (1927-30).

> Teams of young men (were sent) into the South called "Dixie Crusaders" who spearheaded the assault on southern customs (on woods, range, game, and agricultural burning) as their truck caravans rolled through the piney woods broadcasting "with all the drama of the day" . . . . the crusaders traversed 300,000 miles, disseminating two million pieces of literature along the way. More than 5,200 motion picture programs and lectures were presented to three million people, one half of them children, with the USDA film "Trees of Righteousness" enjoying the most universal appeal. By 1923 the woods burner, sought out in his own lair, had been made to know the way of his transgression. "A great tide of indignation", the association asseverated, was sweeping out over the piney woods mobilizing sentiment against the woods burner (Schiff 1962).

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A policy that totally excluded fire was successfully instituted in Florida and southern Georgia; by 1923 the formerly open pine lands in the Thomasville-Tallhassee region became brush-choked, and the quail population drastically decreased. This alarmed the plantation people, who agreed among themselves to finance a scientific investigation to determine why the quail population was declining. They established the Cooperative Quail Study Investigation (1923-28), headed by Herbert L. Stoddard. As early as 1925, in a preliminary report to the supporters of the Investigation, Stoddard pointed out that the absence of fire was the key to the shortage of the Bobwhite quail in this region. He finished his studies 4 years later and published his famous book, "The Bobwhite Quail: Its Habits, Preservation and Increase" (1931). Game management, or wildlife management as we now know it, had really begun. Stoddard was the first to demonstrate scientifically that wildlife was a crop of the land and that wildlife populations could be manipulated through land management practices. He pointed out fire may well be the most important single factor in determining what animal and vegetable life will thrive in many areas (Stoddard 1931).

The Cooperative Quail Study Investigation was succeeded by the Cooperative Quail Study Association, a consulting service that took the research Stoddard and others had conducted and applied it to management plans on more than 100 plantations, averaging about 10,000 acres (4 000 ha) each, scattered from North Carolina to Arkansas. Work was also conducted with several government agencies on the use of fire, but for political reasons most of these preferred not to publicize the fact that they were even interested in burning.

I worked with Stoddard in the Quail Association from 1931 to 1943. We found that on more than 75 percent of the hunting plantations we studied, fire exclusion was the principal factor in declining quail abundance. Other key factors were improper forestry operations and improper distribution of agriculture.

In 1945 my brother, Roy Komarek, and I were asked to manage Greenwood Plantation. The owner, John Hay Whitney, instructed us to "do something to benefit southern agriculture," to develop Greenwood's forests along the lines originally discussed by Stoddard, and to develop game and other resources along the lines recommended in the Cooperative Quail Study Association reports.

The property consists of 18,000 acres (7 300 ha) and is still under our management, so we have had ample opportunity to test our theories and ideas on the use of fire and the production of game animals like quail and many other wildlife species, including song birds. In 39 years of active administration and practical management, the ideas that Stoddard first advocated regarding fire and game management have proved sound.

Henry L. Beadel, owner of Tall Timbers Plantation, had been an original supporter of the Quail Investigation and a prime mover in the organization of the Cooperative Quail Study Association. In 1958 he founded, in cooperation with Stoddard, the Komareks, and many others, Tall Timbers Research, Inc., a foundation whose purpose is "a quest for ecological understanding."

The proper understanding of the place of fire in wildlife management was anchored in the Charter and in Mr. Beadel's will, which gave his 3,000-acre (1200 ha) plantation to the Foundation to be used for its research station.

Beginning in 1962, Tall Timbers Research, Inc., began sponsoring Fire Ecology Conferences, which promoted a better understanding of the use of fire and its many ramifications in nature. The conferences' proceedings brought international recognitio to the Station for its pioneering efforts in this controversial field. Scientists and investigators in many disciplines (forestry, wildlife, agricultur botany, zoology, geography, anthropology, and others) reported on their studies and ideas. More than 400 speakers from 22 countries throughout the world have taken part. Speakers have represented government agencies, private industry, and publicly and privately financed research institutions. There is no doubt that these meetings have done much to stimulate research in fire ecology (a term coined at the first conference, which has since become universally recognized) and the use and management of fire, particularly in wildlife and forestry practices.

The Clarke-McNary Act of 1924 had also spurred fire control and raised the possibility of total fire exclusion in the West, where its effects proved long-lasting. As recently as 1947, Schantz was asked to survey fire in the brushlands of California for the California Forestry Department. His report seldom referred to the possible beneficial use of fire for game habitat management but dealt largely on the destruction of game animals by massive wildfires in the State.

The 14th Tall Timbers Conference was held in 1976 at Missoula, Mont., and was sponsored jointly with the Intermountain Fire Research Council, an organization of Federal, State, and other foresters The first paper presented was "From Fire Control to Fire Management: A Major Policy Change in the Forest Service." Since that conference many studies have been conducted in the West, on the use of fire in forestry practices as well as in wildlife habitat management. Public attitudes have changed to the point that now even commercial timber companies advertise that prescribed burning "sweeps the forest" of flammable debris.

THE PRESENT

In the past decade, the use of prescribed burning to manipulate wildlife habitat and for forestry and range practices has become commonplace in most parts of the United States, though the Northeast still lags somewhat. Prescribed burning is being used even there, however, on barrier islands and on certain lands devoted to range, forestry, wildlife, hunting, and recreation.

An example of public acceptance of controlled burning involves the helitorch, a 55-gallon (200 L) drum filled with jellied gasoline, equipped with an ignitor, and fastened beneath a helicopter. Fires can be ignited by dropping globs of burning jellied gasoline in spots throughout a forest; thousands of acres then burn properly and safely. The use of the helitorch was once considered spectacular and newsworthy, but in parts of the West and in the Southeast its use has become so commonplace it is now largely ignored by newspapers and television.

A great deal of research in fire ecology has focused only on certain facts of fire's relationship to wildlife habitat, which is concentrated, especially in the West, on large game animals. Innumerable studies have established that vegetation regenerated after burning--grass, brush, or even some trees--is always higher in protein, calcium, phosphorus, and other elements necessary for the good health of such animals. It is also widely recognized that such palatable material is absolutely essential for their well-being throughout the reproductive cycle--conception to birth--and during the milk-producing period.

The other emphasis in fire ecology in the last decade or so has been modifying the habitat for game species. Unfortunately, most of these studies investigate only the changes in plant communities and the resulting effects on the bird or mammal population being studied. The impression given is that habitat consists exclusively of cover and structure. The fact that the habitat must have food seems often to be overlooked; yet without the necessary food, any habitat, regardless of its structure and composition, will be of little value to most animals.

For example, over half the families of birds are species with precocial young, able to forage for themselves immediately after hatching. Every study made on any gallinaceous game bird, in the United States, as well as in other parts of the world, has shown that insects and other invertebrate material make up more than 80 percent of the normal diet of these precocious chicks during their first 2 to 3 weeks of life. Fledgling young that are raised in nests, (except for water birds that are fed fish) also are fed for a period of several weeks on nothing but insects or other invertebrates. Studies on related domestic species like chickens or more or less domesticated game birds have shown that a high-protein diet is also necessary in order for the female to lay a large number of healthy eggs. Furthermore, without a high-protein diet, the chicks that hatch will not be strong and may not live. A high-protein diet for song birds is just as necessary as it is for game birds and for the same reasons. Some of the most fruitful and valuable research in the coming decade could focus on the effect of fire on the invertebrate species that play such an important part in the food chain of so many of our wildlife species, particularly during the reproductive cycle.

THE FUTURE

The quality and value of research can be greatly influenced by the institution which produces it. There is real danger that the work of research institutions closely controlled by governmental, or even by commercial, interests will reflect official policy at best--and politics at worst--instead of objective information. The history of fire ecology and its relationship to the ecology of plants and animals as well as humans, shows the dangers of such a "controlled" situation. In his book "Fire and Water: Scientific Heresy in the Forest Service," Schiff (1962) pointed out the dangers and effects of government and academic dominances over fire ecology research during the second quarter of this century and beyond.

The reluctance of government-supported research to document the dangers of some pesticides points up the need for independent, privately financed, nongovernmental biological research organizations to serve the public by presenting impartially all the facts in this vital debate.

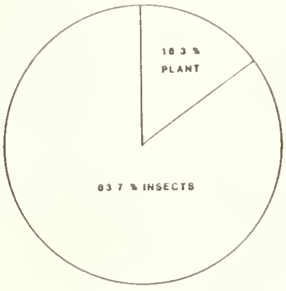
When the founders of Tall Timbers Research, Inc., set up that institution and stated its purpose, they recognized the necessity to develop public and scientific interest in fire ecology through long-term experiments, research, and demonstrations. This meant a research institution well structured and stable enough to guarantee experiment continuity and complete investigative freedom.

"A quest for ecological understanding," the Tall Timbers purpose, cannot be limited to game management alone, and the species studied cannot be only game species. Some of the most fruitful and valuable research in the coming decade could deal with information on the populations, composition, and abundance of such invertebrates as insects, spiders, snails, and earthworms, particularly as they relate to some of our endangered species of vertebrates.

In the past decade or so, the Tall Timbers Research Station has realized the lack of information on the relationship of fire and various invertebrates and has conducted small, rather desultory, studies on the effect of fire on different invertebrates, including insects, spiders, earthworms, and snails. On the basis of this work more extensive studies of insects on the fire plots at Tall Timbers began in 1981.

In 1958, 84 half-acre (0.2 ha) plots were chosen at random all over the 3,000 acres (1 200 ha) of Tall Timbers Research Station on as many different soil types, topography, and conditions as possible. Since the Station's founding, these areas have been burned at specified intervals: annual, biennial, triennial, quadrennial, every 5th year, 7th year, 12th year, 25th year, 50th year, and so on. By design, some were not burned at all. Thus plots annually burned have been burned 25 times in the past 25 years; biennial plots have been burned 12 times; triennial burned 8 times, and so forth. Definitive studies on the insects on these plots began in 1982 and carried on intensively in 1983.

One of the reasons for this intensive study is that Stoddard (1931) had listed more species of insects and other invertebrates (over 400) as food for quail than other species of plants and seeds. All subsequent work on food habits on the Bobwhite quail seems to have focused on seeds and plants in spite of the fact that Stoddard showed that insects made up 82 percent or more of the diet of baby quail in the first 2 weeks of life (fig. 1).



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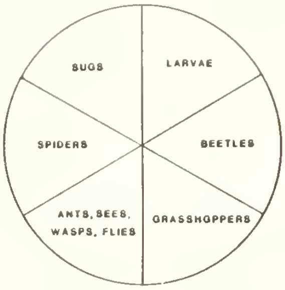


INSECTS CONSUMED

Figure 1.--Diet of Bobwhite quail during first two weeks of life based on research of Herbert L. Stoddard.

Studies in Britain have also shown the value of insect populations to partridge chicks by demonstrating that if insects are not available, the chicks starve to death. In 1970, Hurst also showed that on small quadrats on a burned right-of-way powerline in Mississippi, the diet of baby chicks was almost entirely insects.

In 1982 and in 1983, 1-day-old baby quail chicks were obtained from a propagating plant and fed a variety of insects as well as high-protein mash. It was quickly found that the baby chicks would eagerly go after grasshoppers that had been frozen and thawed out and that apparently they readily ate many species of grasshoppers and many species of miscellaneous insects. In 1983 these experiments were continued in much more detail; figure 2 shows the results. It was soon obvious that 1-day-old baby chicks when given a choice instinctively chose grasshoppers over miscellaneous insects or high-protein mash and that they thereby gained more weight when doing so.

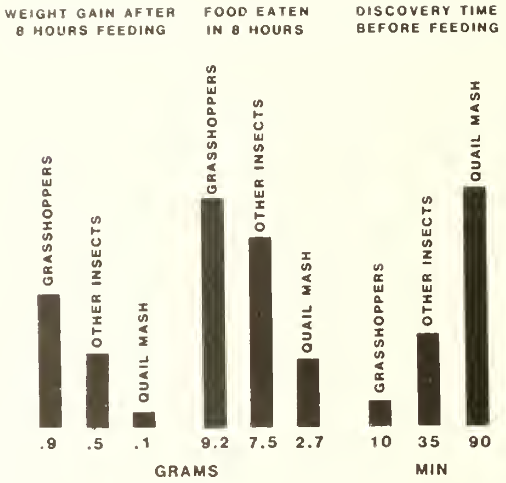
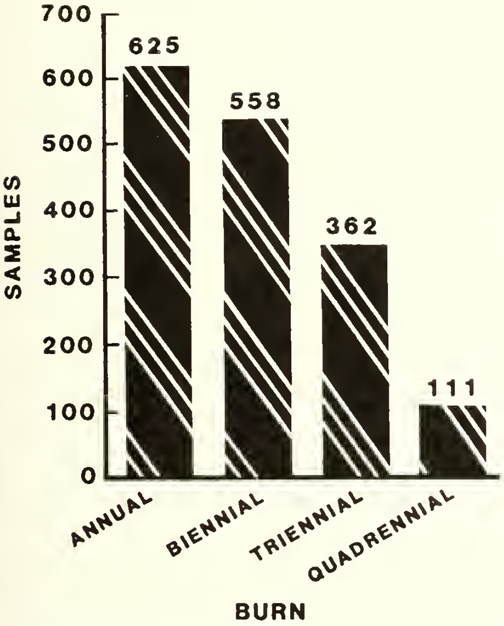


Figure 2.--Response of quail chicks to various foods. Weight and amount of food consumed in 10th of grams over 8-hour period. Discovery time is time elapsed before chicks began feeding.

While these experiments were going on, two quail propagating plants received the wrong mash from their supplier. Instead of a 27 percent protein mash, 20 percent protein mash had been substituted by error. Immediately after feeding with lower-protein mash, the laying hens' production dropped drastically, and eggs did not hatch properly, and the chicks produced were very weak and had a high mortality rate. One week after the mash was replaced by 27 percent protein mash, the quail hens began laying their normal complement of eggs. The eggs that were incubated hatched properly, and the chicks were strong. This demonstrated that the Bobwhite hen, as well as the chicks, requires a high-protein diet. Unfortunately, the average legume seeds on which many of us, including myself, had previously assumed were adequate to feed quail, are not high enough in protein, since they contain only about 20 percent protein.

Once these experiments showed us that quail chicks as well as adult quail apparently readily ate any kind of insect (though there seemed to be some preference for grasshoppers over miscellaneous invertebrates, including spiders), we began intensive, sweeping experiments on the Tall Timbers fire plots. For each collection, each plot was swept 200 times with a 10-inch butterfly net. We then sorted this collection into grasshoppers, miscellaneous insects, larvae, and spiders. Figure 3 shows that on the annually ırned plots there were more Orthoptera in 1983, ıt less on the biennial plots, still less on the :iennial plots, much less in the quadrennial lots, and on the unburned plots few or none at ll. This demonstrated that the periodicity of ire plays a considerable part, not only in plant ıccession, but in insect succession and the kind ıd species that occur.



igure 3.--Orthoptera collected on burned plots by ırning frequency.

ıe grasshoppers in 1982 were identified but ›parently only five or six species are abundant ıough to play a big part in quail diets. As far ; we can ascertain, however, quail showed no :eference in species. Our study also shows that ı 1983 the relationship of fire and Orthoptera ›r the month of July was the same as in 1982, in ›ite of the fact that in March 1983 all the plots l, 2, 3, and 4), were burned. (The reason for ıis burning is that they have to be burned imultaneously every 12 years and 1983 was the ᵎth year of the burning schedule.) Even though ıese plots were burned in March 1983, they show ıe same trend in Orthoptera population as the ›llections made in 1982. What few studies had ɜen made in insects and fire have unfortunately ɜen made only on a 1-year basis, sometimes after period of fire exclusion. Long-term studies ;ing recurring periodicities of fire at varying :equencies, as occurs in nature, are needed. In ıe plots burned every 1, 2, 3, or 4 years, we ıve three major replications, however, because at ıe time we set up the plots we were afraid we ight lose some, an additional three (X, Y, and). Future studies will include all six ɜplications.

Snails

Through many years of burning on Birdsong, as well as in other parts of the world where the land had been burned regularly, my wife and I had often noted an abundance of snail shells. These were not new shells from snails that had been killed by the fire, but evidence that there was a high population of snails--in Africa, Asia, United States--that inhabited regularly burned grasslands. The species most frequently occurring on grasslands in the Thomasville-Tallahassee region are *Triodopsis albolabris* (Say), *T. hopetonesis*, and *Euglandina rosea*. Their abundance shows that these snails are as properly the inhabitants of a regularly burned grassland as are the bobwhite quail or other birds that live there. Even though fire may kill some of them, there is always enough of the population left to recuperate quickly. In 1976 a staff member, Dr. Virgina Vail, studied *Triodopsis albolabris* on an area that had been burned annually for 36 years under my direction. This was a mixed hardwood forest with a few scattered pines. The hardwoods consisted largely of black gum, sweet gum, hickory, and some magnolia and beech. She found that the snail had a remarkable behavior pattern, which allowed it to live in a fire-maintained environment, apparently laying its eggs in places usually protected from fire. Dr. Vail suggests that some of the young and adults take refuge in areas where the surface fire does not reach them (Vail 1978). Even though fires of some intensity do kill a number of snails, by the end of the fall after a late winter burn the population is about what it was before the fire. D. Gillon (1972) and Y. Gillon (1972) found the same egg-laying pattern with insects on the Ivory Coast. Populations of Orthoptera and Hemiptera were somewhat reduced and subject to heavier predation after burning, but after 6 to 9 months, the population was the same as it was before the fire occurred. These studies were made on land that had been burned annually for a great many years.

Salt Water Snails

In studies just initiated it has been found that certain of the salt water snails such as periwinkles (*Littorina*), the common marsh snail *Melampus*, and others apparently also are adapted to fires in salt water marshes. Although these are preliminary results, it does appear that many of these also have behavior patterns that protect them from fire. In one case it was observed with periwinkle (*Littorina irrorata*) that after a purposely set and exceedingly hot experimental fire in needle rush (*Juncus*), the periwinkle had dropped down to the surface of the mud flats, where it was relatively cool. The fire apparently did not kill any, for the next morning the periwinkles all had climbed up on the charred stubble of the vegetation; from a distance it looked like little white specks all over the burned marsh. Curiously enough, Hamilton (1977) found in laboratory studies that this species apparently preferred or went to darkened stalks. In laboratory experiments, where stalks ranged

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from rather light to dark, the periwinkle largely went to the dark. On the marsh burn, we had a field experiment that showed exactly the same thing. The next morning after the burn I was not able to find any dead periwinkles, however, 5 days later the population had diminished somewhat because the stubble was not high enough to keep the periwinkles out of the higher tides (the marsh was burned at low tide), which allowed heavy predation. Apparently with this species, predation is quite a problem, and they seek higher stalks to get away from salt water predators.

At a burn on the St. George Island State Park, also in a needle rush and cordgrass (*Spartina*) marsh, we found that *Melampus* and several other snails appeared to be much more abundant on burned marsh than on unburned marsh. Unfortunately, there seems to be scant literature dealing with the invertebrates of salt water marshes, particularly in needle rush, *Spartina*-type marshes. These marshes are a grassland, so it may be that some of the same principles apply as in burning upland grasslands, although we have an added factor here of high and low tides. Dealing with both fire and water complicates the matter considerably, however, we can state tentatively that fire does not seem to affect the *Juncus* marsh because these marshes have been burned in some areas over a considerable period for livestock range. On the St. Marks National Wildlife Refuge, *Spartina* marshes along the Gulf coast have been burned for many years to provide goose and duck food. There are many studies on the relationship of *Spartina* to fire but practically nothing that applies to the invertebrate life.

Earthworms

In some earthworm studies at Tall Timbers and adjoining regions it has been found that the three commonest species--*Diplocardia mississipiensis, D. longa, and D. floridana*--all inhabit regularly burned open pine woodlands. There are also several other species found in these areas, from small earthworms only an inch or two (1.3 to 5 cm) long (some of which have yet to be described) to *D. longa*, which can be up to 18 inches to 2 feet (45 to 60 cm). The fact that these three species occur only in open fire-maintained pine lands is well known to many local people. On the Apalachicola National Forest, for example, many families make their living harvesting these worms. These people are called "grunters" because they put a staub in the ground and then vibrate it with another one, producing a grunting sound. This vibration brings the worms to the surface, and families can make a reasonably good living collecting them. The earthworms are then processed through sawdust for shipment, often by air, to fishing localities throughout the Southeast. In fact, the Apalachicola National Forest had numerous problems during an almost 20-year period of fire exclusion, because these "grunters" constantly burned holes in the forest in order to maintain the earthworms. Today the Apalachicola National Forest receives an appreciable amount of money every year for the right to collect these earthworms on the forest. The worms are valuable by-product of a slash pine, flatwoods type forest.

All three of these earthworm species occur at slightly different elevations. *Diplocardia floridana* is usually on the highest ground and can occur even on sandy ridges, particularly during exceptionally wet years; *D. longa* seems attracted to an intermediate area of hillocks throughout the flatwoods; and *D. mississipiensis* is in the lowest elevation, sometimes in areas that are wet a good part of the time. In the absence of fire, within 4 to 5 years (as in our plots at Tall Timbers) the grassland disappears and is replaced by hardwood and shrub species. These in turn shade the ground and cover it with their litter, eliminating the grassland, which also eliminates the earthworms. Thus the most abundant species in the flatwoods area of Florida and Georgia, adjacent Alabama and southern Mississippi, and possibly Louisiana, are earthworms that might be terms "fire earthworms," since they only occur in fire-maintained environments. Little detailed study about them has been published. Tall Timbers has done a number of earthworm studies, but most are unpublished.

These four brief examples show an entirely new field, literally untouched by fire ecologists. We know little about the invertebrates of fire-maintained grasslands. On insects there are few studies, and usually these are based on only 1 or 2 years of experiments. I cannot stress too strongly that with the invertebrates (particularly insects, spiders, earthworms, and snails) we are dealing with an important part of the food chain of at least half of the families of song birds and game birds in the United States and of many small mammals, amphibians, and reptiles. Few studies have focused on the recycling of the nutrients in fresh- and salt-water marshes and how these nutrients affect these invertebrates populations. In the past we have paid entirely too much attention to the effect of fire on the habitat as a whole, particularly cover or nesting areas, and not enough to what happens to components of those habitats that serve as food for the birds and mammals and other animal life during their critical periods of reproduction. Investigations of these aspects are greatly needed.

I cannot stress too strongly that almost any study made on fire and its relationship to the invertebrates will be a pioneer venture. Practically everything that an investigator finds will be new to science.

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POSTFIRE SUCCESSION OF AVIFAUNA IN THE OLYMPIC MOUNTAINS, WASHINGTON

Mark H. Huff, James K. Agee, and David A. Manuwal

ABSTRACT: The lower montane zone in the Olympic Mountains (Olympic National Park) was selected to study fire effects in west-slope western hemlock (*Tsuga heterophylla*)/Douglas-fir (*Pseudotsuga menziesii*) forests. Birds were examined along a postfire chronosequence: years 1 to 3, 19, 110, 181, and 515. The objectives of this research were to document the successional patterns of a moist temperate coniferous forest following large lightning fires and to determine the broad ecological effects of fire in these forests. Avifauna that commonly breed in disturbance or mature-type forests were present in postfire years 1 to 3. In year 1, the breeding density and diversity were similar to the nearby old-growth (preburn) forest. Breeding density and diversity decreased in years 2 and 3. The 19-year-old site maintained the highest number of species and second highest density throughout the study areas. Diversity and density were lower at the closed canopy forest, except in the old-growth forest (year 515), where the highest avian density was recorded.

INTRODUCTION

Knowledge of ecosystem processes is essential for the management of natural resources. Fires influence forest ecosystems by altering biotic and abiotic resources, which in turn influence the characteristics of biological succession. Many plant and animal communities are maintained by periodic disturbances, and fire is often the major factor in initiating landscape diversity.

The importance of fire in the long-lived forests of the Pacific Northwest is poorly understood. Regional fire history, plant and animal associations, and successional relationships need to be determined for most vegetation types. The western hemlock (*Tsuga heterophylla*)/Douglas-fir (*Pseudotsuga menziesii Franco var. menziesii*) vegetation zone, extensive on the west slope of the Olympic Mountains and primarily encompassed within Olympic National Park (fig. 1) was chosen as the study region. This research was designed to document the successional patterns of avian communities in a coniferous forest following large lightning fires and to determine the broad ecological effects of fire on bird populations in these forests. We hypothesized that patterns of avian density, species composition, and structure would change with stand age.

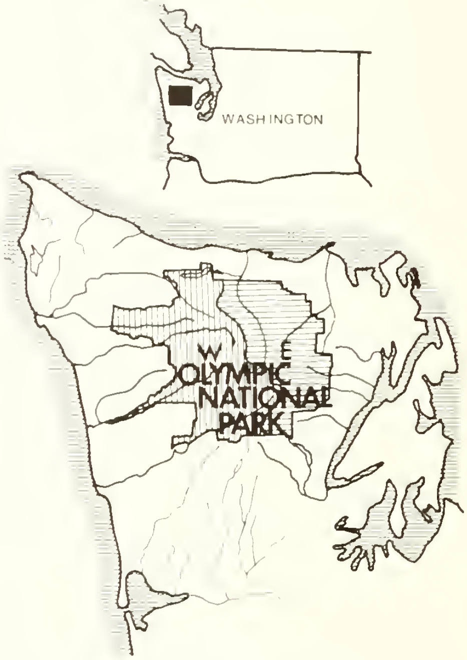

Figure 1.--Geographic location of Olympic National Park.

STUDY REGION

Climate

The Olympic Mountains are an isolated range of precipitous peaks situated on the Olympic Peninsula and in the northwest corner of Washington State (fig. 1). The montane forests that grow on the west side of the Olympic Mountains receive a mean annual precipitation

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etween 225 and 450 cm. Winters are wet and ild. Below 1969 ft (600 m) winter precipitation s mostly rain. During the summer months the aritime air keeps the temperature cooler than in he interior regions of western Washington (Fonda 974). Long summer droughts are possible since he air remains relatively dry during this eriod.

ire

ince 1916, when fire records from Olympic ational Park were first recorded, lightning fires ave been responsible for most of the area burned n the Park. From 1916 to 1979 a total of 7,368 cres (2 984 ha) burned; 83 percent of this area as burned by lightning fires (Huff and Agee 980; Pickford and others 1980). Little is known bout the fire history of the Olympic Mountains efore historical records began. In general, the orests of the eastern Olympic Mountains are ounger than are those of the west side. It has een hypothesized that most of the eastern slope urned about 300 years ago (Henderson and Peter 981). In the western Olympic Mountains, vast xpanses of old-growth forests are found, enerally exceeding 300 years of age. The more oist conditions on the west side have been an mportant factor regulating fire occurrence and ave made these forests less prone to burn. istorically, the west-side fires have occurred nfrequently and are small compared to fires in ther coniferous ecosystems (Heinselman 1981).

egetation

onda and Bliss (1969) have identified five istinct montane forest communities for the orthern and eastern Olympic Mountains, one of hich, *T. heterophylla-P. menziesii*, is common hroughout the lower montane forests of the estern Olympic Mountains. The *T. heterophylla-. menziesii* type is dominated by these two pecies, which comprise 80 to 90 percent of the otal tree density and basal area (Agee and Huff 980; Fonda and Bliss 1969). Western redcedar *Thuja plicata*), widely distributed in this type, arely comprises more than 10 percent of the otal basal area or density. The shrub and herb ayer is poorly developed. Mosses cover most of he forest floor, and only a few herbaceous pecies are present.

vifauna

nformation of forest bird communities of Olympic ational Park is sparse. The information vailable consists only of a checklist of relative bundance for individual species adapted from itchin's 1949 field guide to the birds of the egion. Recently, as this study was being nitiated, Zarnowitz (1982) began a study that easured the effects of logging on bird opulations in Olympic National Forest, an area ordering Olympic National Park. The emphasis was n cavity-nesting species; in addition, avian communities were sampled. A wide range of different-age sites from recent clearcuts to old-growth forests were sampled in western hemlock-Douglas-fir forests. The most common bird species were rufous hummingbird (*Selasporus rufus*), clearcut to year 50; chestnut-backed chickadee (*Parus rufescens*), year 30 to old-growth; western flycatcher (*Empidonax difficilis*), year 30 to old-growth; golden-crowned kinglet (*Regulus satrapa)*, year 30 to old-growth; and winter wren (*Troglodytes troglodytes*), all ages. In general, birds bred in a wide variety of different-age forests, and species diversity was highest in the uncut old-growth forests.

Response of avian communities to wildland conflagrations has not been studied in moist forests of the Pacific Northwest. Fire-related bird studies have been limited to the effects of prescribed burning (Hanson 1978) or population changes by game species (Doer and others 1970; Redfield and others 1970). Outside the Pacific Northwest, wildland fire-related studies on avian communities are also sparse, however, some general trends for western coniferous forests can be synthesized from the research to date (Bock and others 1978; Bock and Lynch 1970; Taylor 1969, 1976; Taylor and Barmore 1980). The first few years after a catastrophic fire, rapid changes in forest structure are evident: the opening of the canopy layer, rapid influx of herbs and shrubs, and the appearance of many standing dead trees. This is a sharp contrast to the structure of a preburn forest. As a consequence of fire, the density and diversity of timber drilling and ground/brush foraging species increase. Of the ground/brush foraging species, insect eaters are more numerous than seed eaters. The flycatching foraging guild shows only minor changes in species composition and density. Tree foliage feeders show sharp decreases (more than the timber foraging guild) in species richness and density following fire. With further forest seral development, the habitat structure changes; avian response is reflected in the reassortment of species adapted to the changes in food abundance and cover. Lowest diversity and density of birds occurs in the thick, closed-canopy forests. As the forest matures, density and number of species increase, yet the increase remains at a lower level than the precanopy stage of succession.

METHODS

Fire effects were documented using the chronosequence approach. This technique assumes that sites of different ages can form a chronological sequence if environmental factors are controlled carefully to ensure similarity among sites (Daubenmire 1968). A chronosequence study must be designed to reduce sampling variability. To accomplish this, the following assumptions were developed for the selection of sample areas:

1. Similar environmental characteristics, ecological stages at the time of disturbance, and disturbance intensity.

2. Stability of species and conditions affecting reestablishment. For the first assumption a set of sample criteria were established after extensive reconnaissance. Each study area was required to have similar (1) aspects (120 to 260 degrees), (2) elevation 1,312 to 2,132 ft (400 to 650 m), (3) slopes (40 to 70 percent), (4) habitat types (western hemlock-Douglas-fir overstory and swordfern ground cover) (Franklin and Dyrness 1973), (5) fire history (burned while in an old-growth seral stage and with extensive overstory mortality).

The second assumption assumes stability of species and climate. These variables are impossible to control; therefore, the role of climate and introduced species must be carefully considered when interpreting results.

Five study areas were chosen in the lower montane zone to represent different stages of postdisturbance stand development over 500 to 600 years (cf. Oliver 1981): stand initiation (Hoh Fire, years 1 to 3, and Queets Fire, year 19); stem exclusion (North Fork Fire, year 110); understory reinitiation (Mineral Creek Fire, year 181); and old-growth (Olympus Guard Fire, year ±515).

In each study area, one bird plot was established to census breeding avifauna. Each bird plot was relatively homogenous in vegetative composition and structure. Adverse terrain prevented the bird plots from being equal in size, but all plots were between 25 and 30 acres (10 to 12 ha).

The spot map method (Kendeigh 1944; Williams 1936), in which bird sightings and vocalizations are recorded on grid maps for each bird plot, was used as the census technique. Bird species, sex, nest site, directional movement, and breeding behavior (for example, song or aggressive interaction) were noted.

Censuses were conducted during the peak activity for most species--0515 to 1000 hours. Because of steep and dissected terrain, a bird plot census took 3 to 4.75 hours and one plot was completed per day. A census of each bird plot was taken eight times spread over the breeeding season (April 15 to July 4). A total of 80 censuses were made: 16 in 1979, 32 in 1980, and 32 in 1981.

Study areas by avian sample years

Study Area	Breeding Season 1979	1980	1981
Hoh Fire	x[1]	x	x
Queets Fire		x	
North Fork Fire			x
Mineral Creek Fire		x	x
Olympus Guard Fire	x	x	x

[1] Breeding season in which bird samples were taken.

RESULTS

Forty-eight bird species were recorded throughout the study areas. Only four species bred in all five study areas: winter wren, chestnut-backed chickadee, hairy woodpecker (*Picoides villosus*), and western flycatcher. The results of the avian community data are presented by study areas and community similarity.

Study Area

Hoh Fire (years 1 to 3, 1979-81)--Despite immediate and extensive tree mortality from the Hoh Fire, during the first 2 years as many bird species were breeding on the Hoh Fire plot as in the nearby (unburned) 515-year-old forest (see fig. 2). After year 2, the diversity dropped from 14 to 11 species. In years 1 to 3, avifauna that commonly breed in either disturbance or mature type-forests were present. Fewer mature forest species that were present after the fire bred in year 3; those missing included the golden-crowned kinglet, Steller's jay (*Cyanocitta stelleri*), and varied thrush (*Ixereus naevius*).

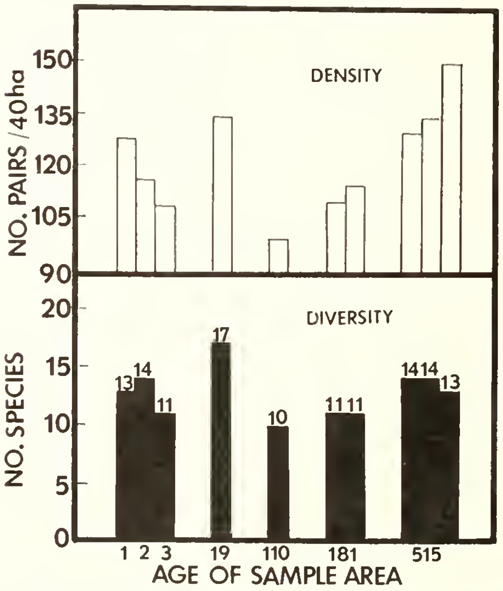

Figure 2.--Density and diversity of breeding birds by sample area.

The bird community at the Hoh Fire year 1 had more dominant species (a species with a breeding density exceeding 10 pairs/100 acres (40 ha)) than any other study area (table 1). These same species were dominant species in years 2 and 3, except the chestnut-backed chickadee, blue grouse (*Dendragapus obscurus*), and western flycatcher in year 3. Winter wrens were the most abundant species in all three breeding seasons (24.9, 29.9, and 44.8 pairs/100 acres [40 ha] respectively). In year 3, nearly three times as many winter wrens were present than the next most numerous species, the dark-eyed junco (*Junco hyemalis*).

Table 1.--Dominant breeding birds on the burn plots

Density dominance (>10 pairs/100 ac (40 ha))

HOH FIRE 1

1. Winter wren
2. Western flycatcher
3. Dark-eyed junco
4. Chestnut-backed chickadee
5. Blue grouse
6. Brown creeper

HOH FIRE 2

1. Winter wren (+)[1]
2. Dark-eyed junco (+)
3. Brown creeper (+)
4. Western flycatcher (-)[2]
5. American robin (±)[3]

HOH FIRE 3

1. Winter wren(+)
2. Dark-eyed junco (-)
3. American robin (+)
4. Brown creeper (-)

QUEETS FIRE 19

1. Dark-eyed junco (+)
2. Rufous hummingbird (+)
3. American robins (+)

NORTH FORK FIRE 110

1. Winter wren (+)
2. Golden-crowned kinglet (+)
3. Townsend's warbler (+)
4. Chestnut-backed chickadee (+)
5. Western flycatcher (+)

MINERAL CREEK FIRE 181

1. Western flycatcher (+)
2. Winter wren (±)
3. Chestnut-backed chickadee (+)
4. Golden-crowned kinglet (±)

OLYMPUS GUARD FIRE 515

1. Western flycatcher (+)
2. Winter wren (±)
3. Chestnut-backed chickadee (+)
4. Brown creeper (+)

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[1] Increase.

[2] Decrease.

[3] No change.

This was the highest breeding density of any species recorded during the study. In year 1, the breeding density of western flycatchers was 21.9 pairs/100 acres (40 ha), but they decreased 50 percent by year 2 and were scarcely observed in year 3 (2.0 pairs/100 acres (40 ha)). This species is a common bird of mature and old-growth forests; it was affected more negatively by habitat modifications from the fire than any other species.

Initially, the Hoh Fire did not alter the total density of birds but did affect species composition. The breeding densities of the old-growth (preburn) forest and Hoh Fire year 1 were virtually identical, at approximately 128 pairs/100 acres (40 ha). In year 2, the total density decreased 10 percent and another 7 percent in year 3. During this period, the bird density in the old-growth forest increased 4 and 17 percent, respectively.

Queets Fire (year 19, 1980).--This plot consisted of a dense to partially open cover of small trees, highly diverse herbs and shrubs, and ample, well-decayed snags in an open setting. This strikingly diverse habitat attracted the highest number of breeding (17) species, and the second highest total breeding density (134.3 pairs/100 acres (40 ha)), even though the fewest number of dominant species (3) were recorded at this study area (table 1). The dark-eyed junco had the highest density (28.4 pairs/100 acres (40 ha)), slightly more than the Hoh Fire population. Because young burns and large open spaces are rare within the western Olympic Mountains, the density of rufous hummingbirds on the 19-year-old plot was probably the highest anywhere on the west slope of Olympic National Park. At this site, hummingbirds were common for at least two reasons: the diversity of flowering herbs and shrubs (nectar feeding) and the open space which benefited their courtship behavior (large circular aerial displays). Winter wren, the most common bird in a montane sere, had lower densities at this stage of succession.

Woodpeckers were rarely observed during this study except on the Queets Fire plot, where four species were recorded: northern flicker (*Colaptes auatus*), pileated woodpecker (*Dryocopus pileatus*), yellow-bellied sapsucker (*Sphyrapicus varius*), and hairy woodpecker (*Picoides villosus*).

North Fork Fire (year 110, 1981).--The most depauperate bird community was observed in year 110. The lowest number of breeding species (10) and density (97.5 pairs/100 acres (40 ha)) were recorded (fig. 2). Certain characteristics of this study area may have made it less attractive to birds: (1) a high density of relatively uniform-size trees, (2) small snags, and (3) lack of diverse vertical structure (a one-layered canopy and poorly developed understory). For example, the 110-year-old site had the highest density of snags yet the lowest diversity and density of hole-nesting avifauna. The absence of certain unidentified food resources may be the most critical factor.

Despite the sparse understory, the winter wren, an understory species, was the numerical dominant (table 1). Only 33 percent of the total bird community regularly lived within the understory component, and the winter wren composed 80 percent of that. The other dominants were canopy dwellers: golden-crowned kinglet, Townsend's warbler (*Dendroica townsendi*), chestnut-backed chickadee, and western flycatcher. Over half of the total birds lived in the tree canopy. The townsend's warbler was the only species to attain its highest density in the 110-year-old forest.

Mineral Creek Fire (years 181 & 182, 1980-81).--Structurally, the 181-year-old plot was most similar to the 110-year-old site, but the trees were larger, understory more developed, and greater vertical structure existed in the canopy layer. Eleven species bred on this plot, one more than the 110-year-old site; however, the density was 15 percent higher (fig. 2). The same species as on the 110-year-old site (western flycatcher, winter wren, chestnut-backed chickadee, and golden-crowned kinglet) were numerically dominant, except for Townsend's warbler. At this stage of succession, the western flycatcher and winter wren were equally the most common species (2-year mean = 26.1 pairs/100 acres (40 ha)). In addition, most of the species that bred at lower densities (<10 pairs/100 acres (40 ha)) were present at both the 100- and 181-year-old sites.

Golden-crowned kinglets attained their highest density in the Mineral Creek study area; however, significant fluctuations were observed between breeding seasons. An eightfold increase in kinglet density was observed between 1980 and 1981. A smaller population explosion of golden-crowned kinglets was recorded on the 515-year-old plot during the same time period.

Olympus Guard Fire (± 515, 1979-81).--The 515-year-old site was used extensively by many breeding and transient species. The old-growth forest offers habitat heterogeneity, which was poorly developed in the 100- and 181-year-old sites. It included a wide diversity of tree sizes from small to large, a higher density of shrub cover, large snags and logs on the forest floor, and massive foliar biomass in canopy dominants.

At this stage of succession, western flycatcher, winter wren, and chestnut-backed chickadee, plus the brown creeper (*Certhia familiaris*) were numerically dominant. The western flycatcher bred at the highest density (3-year average = 36.5 pairs/100 acres (40 ha)), noticeably more than the next most common species, the winter wren (3-year average = 27.4 pairs/100 acres (40 ha)). Compared to the 110- and 181-year-old forests, more bird species reached their highest population level in the old-growth forest: western flycatcher, chestnut-backed chickadee, brown creeper, and varied thrush. In addition, total density of hole-nesting birds was maximized on the 515-year-old plot. The total density of birds increased each breeding season from 1979 to 1981; however, no species increased in population all three seasons. The 1981 census showed the highest density of birds recorded during the study 149.5 pairs/100 acres (40 ha)).

Community Similarity

Similarity of species composition between sample areas and breeding seasons was examined. Nearly all of the coefficient-of-community values were above 50 percent (see table 2), meaning that more similarity than dissimilarity existed. Of all th sample areas, the Queets Fire (19-year-old site) avifauna was the most dissimilar. Compared to th other study areas, the Queets Fire habitat was unique; it included many small trees in open and dense patches, a lush herbaceous and shrub component, and the lack of tree canopy. The avia community of the 19-year -old site most closely resembled the other open plot sampled at the Hoh Fire site. The bird community of the Hoh Fire 3 was more closely related to the Queets Fire avifauna than was Hoh Fire years 1 and 2. Hoh Fire years 1 and 2 resembled the avifauna of the old-growth (prefire) plot more than the 19-year-old burn.

Similarity was highest within the closed forests: North Fork (110), Mineral Creek (181), and Olympu Guard (515) study areas. Even though more than 300 years of seral development separated the Mineral Creek and Olympus Guard sites, the similarity of species was over 90 percent.

The similarity between sample years was 10 to 21 percent higher in the closed forest sites (Mineral Creek and Olympus Guard Fires) than the Hoh Fire plot (table 2). At both the Olympus Guard and Hoh Fire sites, however, the similarity was higher between successive breeding seasons (year 1 and year 2 or year 2 and year 3) than alternate breeding seasons (year 1 and year 3).

DISCUSSION

We hypothesized that bird populations would chang significantly with respect to stand age (time since last burn). Because of the rapid shifts in species composition and density, the changes were more evident during the pioneer stages of succession. During the first few years after a fire there is an influx of new species (not commonly found in the old-growth forest) intermixed with most of the "old-growth" type species. The burned habitat goes through rapid physical and biological changes not characteristi of an old-growth forest; it is likely that the burned forest harbors relatively unstable food resources.

Table 2.--Matrix of coefficients of community[1] for breeding avifauna

Sample site year	HF 1 1979	HF 2 1980	HF 3 1981	QF 19 1980	NFF 110 1981	MCF 181 1980	MCF 182 1981	OGF ±515 1979	OGF ±515 1980
HF 1979									
HG 1980	81.5								
HF 1981	75.0	80.0							
QF 1980	60.0	64.5	64.3						
NFF 1981	60.9	58.3	47.6	37.0					
MCF 1980	66.7	64.0	54.5	37.0	76.2				
MCF 1981	66.7	80.0	54.5	50.0	76.2	90.0			
OGF 1979	66.7	71.4	56.0	51.6	75.0	80.0	80.0		
OGF 1980	66.7	78.4	56.0	51.6	66.7	80.0	80.0	92.6	
OGF 1981	69.2	81.5	58.3	53.3	69.6	83.3	91.7	88.9	96.3

[1] Percent similarity = $\frac{2c}{a+b}$ x 100 where c = number of species in common between study areas a and b; a = number of species in study area a; b = number of species in study area b.

Taylor and Barmore (1980) studied bird populations along a postfire vegetation sequence ranging from 1 to 304 years in Yellowstone and Grand Teton National Parks. They grouped birds in order of appearance and disappearance in the time sequence. More species were unique to the early stages (1 to 17 years) than to the later stages (111 to 304) years of succession. Forty-three percent of the birds in the early successional plots bred only on these plots; on the contrary, 7 percent of the late successional species bred only in the late successional plots. In comparing the bird populations in the Olympic Mountains, a somewhat similar trend was detected: 30 percent and 11 percent, respectively, but the percentage of early successional birds was noticeably higher in Yellowstone and Grand Teton National Parks. Because fires occur more frequently in this region of the Rocky Mountains (Romme 1982), more habitat is available for species that prefer recently disturbed over not recently disturbed habitats. This attracts more species that specialize in early seral stages, more so than the Olympic Mountains where fire-disturbed habitat is sparsely distributed.

Bock and Lynch (1970) censused bird populations in a *Pinus jeffreyi/Abies concolor* forest 6 to 8 years after a fire along with a mature forest (preburn) control plot. After 7 years elapsed, these plots were remeasured (year 15) (Bock and others 1978). The changes in bird species in the two sampling periods were far greater on the burn plot than in the mature forest. On the burn in year 8, the avian species more closely resembled those in the mature forest than those in the 15-year-old forest. The habitat structure by year 15 was so different from the preburn forest (control plot) that a distinct avian community had developed.

In the Olympic Mountains, as in the California plots, there is a high similarity between the bird species breeding in the early postfire plots (years 1 to 3) and the preburn forest (year 515), more so than the bird species breeding at year 19. Unlike the California plots, avian diversity was much lower in the early postfire plot compared with further successional development in year 19; however, since postfire revegetation is so slow in the Olympic Mountains, a 19-year-old forest may structurally resemble a considerably younger forest in California. If so, a longer period of high avian diversity can be expected with a slow reestablishment period in the Olympic Mountains. Once a full tree canopy develops in the Olympic Mountains, there are few changes in bird species composition. Even though a forest may develop over several centuries, the type of species breeding in these seres changes very little.

CONCLUSIONS

1. Relatively few bird species breed in the montane forests of the Olympic Mountains.
2. Because fire modifies the vegetation composition and structure, there are changes in density and species composition of the bird communities.
3. A unique avifauna bred on the younger burns; however, species that commonly breed in a preburn forest also breed in the very early postburn forest.
4. The highest diversity of birds occurs in the 19-year-old forest and the highest density in the old-growth forest.
5. The most common species in the montane forest sere are the winter wren (young and old sites) and western flycatcher (primarily 110-, 181-, and 515-year-old sites).
6. During the early stages of succession, populations of western flycatcher are negatively affected by fire more than other species.
7. Fire enhances the habitat resources for ground/brush-foraging species; increased diversity and density of this guild are observed in the first few years after fire.

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FIRE'S EFFECTS ON A SMALL BIRD POPULATION

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ABSTRACT: Changes in bird populations as a result of a 122 ha forest fire are evaluated. There is little evidence of any drastic effect on numbers of birds, species, or species diversity in the year of the fire or 2 years later.

INTRODUCTION

The influence of fire on small bird populations is most often visualized in the context of the Smokey Bear poster showing a female robin on the nest--and the obvious implication that the bird, and the eggs or young, will be burned to a crisp if someone is careless with matches. A somewhat more pragmatic view suggests that direct mortality, even in large forest fires, is a relatively unusual event (Vogl 1967; Phillips 1965; Stoddard 1963). Nevertheless, modification of important niches in the habitat might be as lethal as fire if the bird is unable to find other, equally suitable, places to feed and nest. Bendell (1974), for example, concluded that bird species that forage on the tree trunk and in the canopy may be eliminated from burned areas but that ground feeders may be attracted and benefited. Overall, his summary of 22 reported studies suggests remarkable stability, although the postfire avifauna might be slightly richer. There is also some possibility of a shift to larger birds (Bock and Lynch 1970; Martin 1960).

STUDY DESCRIPTION

Study Areas

As a part of an exploratory investigation of small bird habitat utilization on the Lolo National Forest in 1979, we selected 21 representative 5-ha study sites in the Lolo Creek drainage. Our locations included habitats varying from ponderosa pine (*Pinus ponderosa*) types at 1 052 m to Engelmann spruce (*Picea engelmannii*)-subalpine fir (*Abies lasiocarpa*) types at 1 628 m. Representative forest communities ranging from clearcuts to old-growth timber stands were selected. Results of the first year of study were reported by Marzluff and Lyon (1981, 1983). Field work was repeated i 1981 on the same areas by Lucia Settimi under a contract with the U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station.

On July 20, 1979, two of the study areas burned i a forest fire. The burned area was relatively small (122 ha), but the fire was intense, and it appeared to destroy all green vegetation at groun level and many of the tree tops. In this paper, we report the immediate response of birds to this drastic change in the environment and the apparen effect on bird populations 2 years later.

Of the 21 areas on which birds were counted, none were considered directly comparable to the two that burned. The Mill Creek upland site that burned (MCB) was located adjacent to another upland site with fewer trees but in a similar forest community. This area, Mill Creek unburned (MCU), was not disturbed in the fire. The Mill Creek riparian area (MCR), so designated because of its location on the first bench above the cree was virtually unique; however, we had another are about 14 km away, near the Lewis and Clark campground (LCC) that was also adjacent to a flowing stream. For comparative purposes in these analyses, we have included both burned and unburned areas, but it should be recognized that the four study sites are only comparable in that all are south of Lolo Creek on generally north aspects, all were unlogged until after the fire, and all are in a similar forest community mostly dominated by Douglas-fir. All areas were classified as Douglas-fir/*Physocarpus malvaceous* habitat types (Pfister and others 1977), although MCR and LCC both had some Engelmann spruce and several species of large shrubs that indicate a slightly more mesic condition than the two upland sites, MCB and MCU.

Field Methods

Bird censuses were taken in both years of study a about 2-week intervals in the period between June 15 and September 15. Working between a half hour before sunrise and noon, observers walked slowly along a transect 500 m in length and recorded all birds seen or heard within a belt approximately 100 m wide. A 3-minute pause at each of 20 permanently marked transect points allowed the observer to carefully scan the area for nonsingin or inactive birds.

Vegetation data were recorded in each of 20 circular plots, 5.6 m in radius (100 m^2), spaced at 25 m intervals along the transect. Data

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included categorical classifications for percentage cover (0 = 0%, 1 = <5%, 2 = 5-25%, 3 = 25-50%, 4 = 50-75%, and 5 = >75%) within each of six vertical intervals (0.0-0.5 m; 0.5-1.5 m; 1.5-2.5 m; 2.5-8.0 m; 8-25 m; and >25 m); number of live and dead stems in six diameter classes (0-2 cm, 2-5 cm, 5-10 cm, 10-25 cm, 25-50 cm, and >50 cm); live and dead basal area; counts of dead and down stems; slope; aspect; and elevation. Vegetation sampling was repeated in 1981 to detect any permanent changes in habitat structure. We are indebted to Kenneth Pitt for completing the 1981 sampling under the Volunteers in Service program of the U.S. Department of Agriculture, Forest Service.

Analyses

The test hypothesis of primary interest was whether numbers of birds or the bird community structure were significantly changed as a response to changes in the habitat. Initial examination of the data, however, revealed substantial changes in species composition during the 2-week observation cycles and a significant decline in numbers of birds observed in the second year of study. Thus, it became necessary to compare all analyses on the burned areas with similar analyses of comparable unburned areas in an attempt to recognize changes unrelated to the fire. Data were compiled and examined with variance analysis in matrixes using combinations of the following categories two at a time:

Season, N=6 (June, July A and B, August A and B, September)
Guild, N=8 (feeding guilds, see footnote, table 3)
Area, N=4 (two burned, two unburned).

In a few instances, it was possible to combine two selected categories with years in a three-way factorial analysis; however, this design was not considered statistically acceptable if it forced us to interpret first- or second-order interactions that were even slightly obscure. Thus, our analyses are broken up into a series of smaller analyses rather than the large factorial: Years X Areas X Seasons X Guilds.

Each variance analysis was replicated to test for differences in numbers of birds recorded, numbers of species recorded, and average weights of birds observed. We also examined changes in species composition of bird populations observed on each area by season and calculated the Shannon/Weiner diversity index (see Krebs 1972:506) for each replication in an Area X Season matrix.

STUDY RESULTS

Changes in Available Habitat

All study transects were evaluated in 1979 and again in 1981 to determine changes related to vegetation regrowth and/or salvage logging. Averages for cover category estimates, stem densities, and basal areas, 1979 and 1981, on four study areas are presented in table 1.

A common perception about the effects of fire in a coniferous forest is that the postfire community will consist of blackened stems with bare branches. In fact, unless a forest fire sweeps through the crowns, it is possible to kill the trees without even removing the needles. For some period after the fire, the ground surface may be blackened and bare, but the cover above ground level, and particularly above 1.5 m may not be perceptibly different than before the fire. As a general rule, needles scorched by ground fires will turn brown in the first 2 weeks, and in some cases the scorched trees may even recover.

Both burned areas in this study retained some cover at all levels following the fire. The most noticeable characteristics of the burned areas in mid-August 1979 were a broad layer of ash 2 to 5 cm deep, and a lack of green vegetation below 2.5 m, but there were small patches of unburned vegetation at ground level and considerable amounts of green canopy interspersed with the brown-needle cover above 2.5 cm. Three sample points on MCB remained unburned, and although the majority of tree boles were scorched on both transects, the crowns of some mature trees were still green 3 weeks after the fire. The immediate habitat change on MCR was somewhat greater than on MCB because the preburn community had an understory component of large shrubs. These lost all their foliage even though many of the stems were still present.

In the 18 months following the fire, the landowner completed a salvage logging operation in which the majority of the larger trees were removed. About the same basal area was removed from both areas, but MCB had fewer stems in the large-diameter classes, and as a result, the remaining forest stand in 1981 was similar to the undisturbed area MCU except for a greater basal area of snags. By contrast, the riparian burned area, MCR, was almost completely salvage logged. The removal of all stems over 15 cm resulted in a substantial loss of both tree cover and basal area. By 1981, however, the shrub understory had resprouted, and cover up to a height of about 1.5 m was only slightly less than that recorded before the fire.

In addition to structural changes in the habitat, we also noticed an immediate postfire increase in apparent numbers of a variety of insects that had not been commonly observed before the fire. Charles F. Tiernan, Forest Service entomologist, conducted a brief survey of the burned area for us, and reported intense insect activity involving at least four species of wood borers (genera *Buprestis*, *Monochamus*, *Neoclytus*, *and Agrilus*); ichneumonid females (parasites of wood borers); and predaceous flies of the families Therevidae and Asilidae. Attraction of insects to either the smoke or heat of forest fires has previously been reported (Evans 1971). On both of the burned study areas, we observed almost frenetic feeding activity among warblers and a few species of woodpeckers.

Table 1.--Cover category means, number of stems, basal area and snag basal area on four study areas in the Lolo Creek drainage, 1979 and 1981

Area	Mill Creek-Burned 1979	Mill Creek-Burned 1981	Mill Creek-Unburned 1979	Mill Creek-Unburned 1981	Mill Creek-Riparian 1979	Mill Creek-Riparian 1981	Lewis & Clark Campground 1979	Lewis & Clark Campground 1981
Average cover[1]								
25 m+	0.10	0.05	0.05	0.05	0.25	0.00	0.00	0.00
8.0-25 m	0.95	0.75	0.80	0.80	1.35	0.05	1.85	1.85
2.5-8.0 m	2.15	1.40	0.95	0.95	1.80	0.15	2.10	2.10
1.5-2.5 m	1.20	1.25	0.85	1.00	2.25	0.50	1.45	1.45
0.5-1.5 m	1.55	1.50	1.55	1.55	3.15	2.10	1.85	1.85
0.0-0.5 m	4.95	5.00	5.00	5.00	5.00	4.90	4.90	4.90
Numbers of Stems/ 100 m^2								
50 cm+	0.05	0.00	0.05	0.00	0.15	0.00	0.00	0.00
25-50 cm	0.30	0.05	0.20	0.20	1.05	0.00	1.10	1.10
10-25 cm	3.90	0.90	1.25	1.50	2.40	0.10	5.45	5.50
5-10 cm	4.90	1.25	0.90	1.15	1.30	0.15	3.95	3.85
2-5 cm	3.45	0.65	1.00	1.30	0.70	0.10	1.95	1.50
<2 cm	2.85	0.20	2.10	2.15	1.20	0.00	0.65	0.50
Basal area, m^2/ha	3.27	0.48	0.94	1.06	2.94	0.01	4.35	4.27
Snag basal area, m^2/ha	0.29	1.32	0.09	0.14	0.38	0.57	0.46	0.42

[1] Cover categories scaled 0-5: 0 = 0, 1 = < 5%, 2 = 5%-25%, 3 = 25%-50%, 4 = 50%-75%, 5 = > 75%.

Changes in Bird Species and Numbers

In the initial analysis of variance, each study area was examined in a 6 X 8 matrix of Seasons X Guilds. This analysis did not prove to be informative. Almost without exception, there were significant differences among guilds and no differences among seasons. Throughout all observations on all study areas, the two guilds including insect feeders contained more birds and more species than all other guilds combined.

Analysis of the 4 X 6 matrices of Areas X Seasons was more revealing. In 1979, an average replicate produced observations of 36 birds of 10 species (table 2). In 1981, the overall means dropped to 20 birds and 8 species. Seasonal differences were significant only in 1979, but a consistency can be detected in both years. Immediately following the fire, in 1979, there was a significant depression in numbers of birds seen and a concurrent depression in the numbers of species. This depression occurred on both the burned and unburned areas, although it appeared to be slightly more severe in the burn. A similar depression was recorded 2 weeks earlier in 1981, and in both years, the depressed counts were followed by substantially increased counts as immature birds and family groups began to move about and flock before migration. Because the immediate postfire decline was slightly greater on burned areas, the increases also seem larger for the burn, but there is actually nothing in these data to indicate that the burn was anything more or less than a favorable transitory hunting opportunity. In 1981, the four species primarily involved in the apparent increases repeated similar patterns of increased abundance in late August, although actual numbers were somewhat subdued because of an overall decline in insectivorous birds. Numbers of chipping sparrows, yellow-rumped warblers, golden-crowned kinglets, and Townsend's warblers increased dramatically during this period.

Analysis of the 4 X 8 matrices of Areas X Guilds (table 3) confirmed the already-mentioned dominance of insect feeders in these bird populations. Overall, the numbers of birds and numbers of species that feed on insects in the foliage was significantly greater than the numbers and species of insect feeders on the ground, which, in turn, exceeded any other feeding guild.

Further examination of the numbers of birds recorded by guild reveals that, although maintaining numerical superiority, insect feeders suffered a disproportionate share of the decline in numbers of birds recorded between 1979 and 1981. Analysis of variance of the factorial design Years X Areas X Guild demonstrates a significantly greater decline in the two insect feeding guilds than in other guilds. Foliage insect feeders, in particular, declined to only a third of the numbers seen in 1979.

Several other high and low numbers in table 3 seem worthy of examination, although in no case were

Table 2.--Numbers of birds and numbers of species, Area X Season for 1979 and 1981

Area	Season						Area sum
	June	July	A.......B	Aug.	A.......B	Sept.	
1979			Numbers of Birds				
Mill Creek-Burned	36	33	42	14	61	29	215
Mill Creek-Unburned	34	31	51	23	81	43	263
Mill Creek-Riparian	28	45	46	9	62	29	219
Lewis & Clark Campground	23	28	26	18	56	16	167
Season sum	121	137	165	64	260	117	Mean=36
1981							
Mill Creek-Burned	30	30	24	26	17	18	145
Mill Creek-Unburned	27	29	18	43	16	5	138
Mill Creek-Riparian	19	15	10	31	2	18	95
Lewis & Clark Campground	16	23	6	11	33	9	98
Season sum	92	97	58	111	68	50	Mean=20
1979			Numbers of Species				
Mill Creek-Burned	9	9	9	6	10	7	50
Mill Creek-Unburned	14	9	15	11	13	14	76
Mill Creek-Riparian	14	14	12	3	13	10	66
Lewis & Clark Campground	7	9	9	7	9	6	47
Season Sum	44	41	45	27	45	37	Mean=10
1981							
Mill Creek-Burned	6	12	8	7	5	7	45
Mill Creek-Unburned	14	13	11	15	7	4	64
Mill Creek-Riparian	10	8	3	11	2	6	40
Lewis & Clark Campground	6	8	4	6	9	6	39
Season sum	36	41	26	39	23	23	Mean=8

Table 3.--Numbers of birds recorded, Year X Area X Guild[1]

Area	Feeding guild								Area sums
	GS	FS	GI	FI	AI	TD	TG	AO	
1979									
Mill Creek-Burned	6	23	83	78	3	7	15	0	215
Mill Creek-Unburned	14	29	59	108	6	7	38	2	263
Mill Creek-Riparian	8	33	37	115	17	3	6	0	219
Lewis & Clark Camp	5	6	28	112	4	0	12	0	167
Sums	33	91	207	413	30	17	71	2	864
1981									
Mill Creek-Burned	26	22	56	14	12	5	3	7	145
Mill Creek-Unburned	4	19	39	34	16	4	18	4	138
Mill Creek-Riparian	9	10	21	34	11	1	3	6	95
Lewis & Clark Camp	1	18	3	52	2	1	15	6	98
Sums	40	69	119	134	41	11	39	23	476
Guild Totals	73	160	326	547	71	28	110	25	

[1]	Guild	(representative species)
GS	Ground seed feeders	(dark-eyed junco)
FS	Foliage seed feeders	(pine siskin)
GI	Ground insect feeders	(chipping sparrow)
FI	Foliage insect feeders	(yellow-rumped warbler)
AI	Aerial insect feeders	(flycatchers)
TD	Timber drillers	(hairy woodpecker)
TG	Timber gleaners	(red-breasted nuthatch)
AO	All others	

the relationships found to be statistically significant. The high count for insect feeders on the ground (GI) on MCB in 1979, for example, traces to flocks of chipping sparrows seen both before and after the fire. The high count for timber gleaners on MCU traces to two flocks of mountain chickadees. These birds were recorded after the fire burned through the adjacent forest, and the observations might be interpreted to indicate that chickadees were attracted to the general area of the burn. It also seemed meaningful to us that the decline in numbers of timber gleaners from 1979 to 1981 seems to have been disproportionately larger on the two areas that were burned and that numbers of seed feeders on the ground (GS) on MCB was quite high in 1981. These observations appear to confirm Bendell's (1974) conclusion that species which forage on the tree trunk may be eliminated whereas ground feeders may be benefited. On the other hand, Bendell's conclusion that fire will eliminate bird species which forage in the canopy was not confirmed.

Changes in Average Weights of Birds

Analyses examining average weights of birds observed proved to be confusing and not particularly informative. With only one exception, there were no differences among areas or seasons, whereas differences among feeding guilds were always extremely high. These differences among guilds, however, were not consistent. In almost every analysis we found that significant differences were associated with the observation of a single bird. A ruffed grouse or a large hawk would produce statistical significance in any category, and even when these species were removed from the data, a single mourning dove, Steller's jay, or northern flicker would raise the average weight of birds in a guild to a significant level.

The only analysis in which weight differences could be interpreted in a meaningful context involved the seasonal movement of Clark's nutcrackers from higher elevations to the general elevation of Mill Creek in September. Arrival of the nutcrackers made average weights of birds in September significantly higher than in previous observation periods.

Changes in Bird Species Diversity

Shannon/Weiner diversity for 6 replications of field counts on 4 study areas ranged from H = 1.2 to 3.6 (mean = 2.7) in 1979 and from H = 1.0 to 3.6 (mean = 2.5) in 1981 (table 4). Analysis of variance revealed no significant differences among areas or seasons in either year of study, and we could detect no certain influence of the fire on bird species diversity. Examination of individual observation means, however, reveals that one or more H were outside the $P < 0.01$ confidence interval for the overall mean in both years. In 1979, $2.3 < H < 3.1$, and in 1981, $2.1 < H < 2.9$. Of the H outside these ranges, the most interesting is probably the low index for MCR in the first observation period after the burn. Only 9 birds of 3 species were observed, whereas 2 weeks later, the same area produced 62 birds of 13 species. Because this decline in diversity was not duplicated on the adjacent burned area, MCB, we can only speculate about the consistency of the influence of fire. These data supply no indication that burned areas had higher or lower diversities than unburned areas, but there is a strong implication for population instability on recently burned areas. In 1981, despite the passage of two growing seasons in which there was some vegetation recovery, the average change in H from one observation period to the next was more than twice as great on burned areas as on areas that remained unburned.

Table 4.--Shannon/Weiner diversity indices (H) for six replications on four study areas, 1979 and 1981

Area	June	July A	B	Aug. A	B	Sept.
1979						
Mill Creek-Burned	2.82	2.33	2.51	2.41	2.64	2.36
Mill Creek-Unburned	3.28	2.45	3.43	3.05	2.97	3.18
Mill Creek-Riparian	3.61	3.40	3.06	1.22	3.13	2.25
Lewis & Clark Campground	2.49	2.92	2.82	2.44	2.49	1.62
1981						
Mill Creek-Burned	1.87	3.12	2.65	2.47	1.89	2.68
Mill Creek-Unburned	3.63	3.37	3.09	3.44	2.42	1.92
Mill Creek-Riparian	2.97	2.87	1.16	3.09	1.00	1.97
Lewis & Clark Campground	2.31	2.49	1.79	2.37	2.77	2.42

This observation prompted us to develop an expression of the relative turnover rate in bird populations from one observation period to the next. The proportions presented in table 5 are calculated as the ratio of the number of species seen in one or the other of two observation periods, but not both, to the total number of species seen both observation periods. We were surprised to find that a turnover rate in excess of 50 percent was not unusual. On all four areas, in an average 2-week period, more than half of the species identified were replaced by other species. Despite this already existing high replacement, we found that turnover increased substantially following the fire in 1979, and it appears that the habitat changes on MCR were great enough to continue this high turnover rate into 1981. During the course of this study MCR was modified far more than MCB, and it appears that the removal of most of the cover above 1.5 m produced a less desirable small bird habitat.

Table 5.--Relative turnover rates in species composition from one observation period (season) to the next

Area	June	July A	July B	August A	August B
1979					
Mill Creek					
-Burned	0.800	0.615	0.636	0.667	0.786
-Unburned	0.722	0.588	0.471	0.400	0.773
-Riparian	0.444	0.471	0.846	0.857	0.722
Lewis & Clark Campground	0.667	0.364	0.364	0.545	0.750
1981					
Mill Creek					
-Burned	0.733	0.824	0.636	0.667	0.800
-Unburned	0.773	0.588	0.700	0.778	0.778
-Riparian	0.800	0.900	0.883	0.818	1.000
Lewis & Clark Campground	0.833	0.800	0.750	0.636	0.750

Observations and Field Notes

Throughout the compilation of these statistical ests we held in abeyance the recognition that ome observations simply cannot be tested. The lmost total dominance of these bird populations y insect feeders tends to obscure the fact that changes in some of the less abundant guilds or ndividual species may have been ecologically mportant even though the available data provide o potential for demonstrating statistical ignificance.

We were able to demonstrate that the number of birds observed increased significantly after the middle of August 1979 and further, that these arge increases primarily involved insect feeders. We were unable to show that some species of insect feeders, notably MacGillivray's warbler, Swainson's thrush, and the warbling vireo, disappeared from the burned areas immediately after the fire.

The Swainson's thrush was not seen in either burned area in 1981, and we have presumed this to be an indication that too much canopy was removed to leave a desirable habitat. MacGillivray's warbler, on the other hand, returned to the same areas occupied in 1981 and repeated an identical disappearance pattern in late August. In 2 years, including data from all the other study areas in the Lolo Creek drainage, only one MacGillivray's warbler was recorded after the middle of August at an elevation below 1 250 m.

Observations made of the warbling vireo were inadequate to demonstrate whether the species responded to habitat change, is an early migrant, or simply reacted to a short-term, locally favorable feeding situation caused by the fire. In 1979, the number of vireos recorded on MCU increased after the fire. Numbers of several other species also increased on MCU at this time, and our initial impression was that MCU was receiving some spillover of birds displaced from the nearby burned areas. Too few vireos were observed in 1981 to determine whether the burned areas continued to be less acceptable than the adjacent unburned area, but we did determine that the vireos observed in 1979 were the only warbling vireos recorded after mid-August on any area in the Lolo Creek drainage in either year of study. This suggests a possibility that the specific foraging opportunity available in MCU following the fire enabled vireos to remain in the area longer than is usual for this species.

In a number of ways, the data describing small bird use of area MCU seem somewhat unusual. There is a general impression in our data of a very favorable small bird habitat. For both years of study, MCU averaged more birds, more species, and a higher ranking of the diversity index in comparisons with the other study areas. It is our impression, however, that this attraction for birds is somewhat greater than might normally have been expected in a plant community of this structure. The location of MCU, immediately adjacent to the two burned areas, has created a relatively unique combination of habitat diversity and edges that make this specific site and the surrounding area appear far more attractive and productive than it really is.

Our final observation from our field notes involves the several species of woodpeckers recorded during the study. Birds classed as timber drillers in 1979 increased from 5 before the fire to 12 after the fire. This difference, since it involved such a small number, was not significant even though 10 of 12 woodpeckers were recorded in the burned areas. In addition, it seemed important to us that these observations included the only northern three-toed woodpeckers seen in 1979 and that this species was seen only on a burned area in 1981.

SUMMARY AND CONCLUSIONS

In the data presented here, there was surprisingly little evidence that the Mill Creek fire of 1979 had any drastic effect on numbers of birds, numbers of species, or species diversity--either during the year of the fire or 2 years later. Considering only the data from the burned areas, it might have been concluded that an immediate postfire depression in bird numbers and a subsequent substantial increase were fire-associated phenomena. A majority of the bird species recorded were insect feeders, and one of the immediate changes in the burned area was a sudden increase in insects attacking the burned trees. Apparently, however, an increase in numbers of birds observed after the end of July is a predictable annual occurrence related to movement by family groups and flocking before migration.

One immediate physical effect of the fire was removal of much of the cover below 2.5 m and thinning of the canopy above that height. Salvage logging further reduced the canopy, especially above 2.5 m. These changes were potentially significant for a few species, but for small bird populations as a faunal group, the influence of the burn was relatively subtle and appeared to cause modifications in patterns of habitat use rather than any strong attraction or avoidance of the modified habitat. The Mill Creek fire, because it was small, and possibly because it was not a completely destructive burn, may actually have increased habitat diversity for the larger area including the unburned forest immediately adjacent to the burn. At the same time, this increased habitat diversity was accompanied by an increase in species turnover from one biweekly observation period to the next.

One of the more significant observations presented in this paper has little to do with the influence of fire. During the summer of 1980, western Montana was subjected to a fine-grain ash fall following the eruption of Mount St. Helens. There was some conjecture at the time about the influence this ash fall might have on insect populations and, potentially, on other fauna dependent on insect foods. We believe the available data indicate a very substantial influence of ash fall on nesting success by insect-eating small birds. We cannot report with certainty that 1980 was a poor year for nesting success by insectivorous birds in western Montana, but such an event would explain the decline in numbers of birds observed in 1981. Data from 19 unburned study areas represent a much larger evaluation base than the four study areas examined here, and we are evaluating those data for presentation in the future.

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FIRE, LOGGING, AND WHITE-TAILED DEER INTERRELATIONSHIPS IN THE SWAN VALLEY, NORTHWESTERN MONTANA

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ABSTRACT: The historical importance of fire was investigated on the upper Swan Valley winter white-tailed deer range in northwestern Montana. The relatively recent impacts of logging on winter range quality were also included in these studies. Fire exclusion has led to successional development of once open-canopied mature seral forests, and the original fire-maintained vegetation mosaic became altered. Thirty years of timber harvesting treatments, including the clearcutting of large blocks of the winter range, has effectively interrupted the natural deer use patterns on this winter range.

INTRODUCTION

The white-tailed deer (*Odocoileus virginianus*) is an important big game species throughout much of western Montana, and its distribution is closely associated with the lower coniferous zone, characterized by Douglas-fir (*Pseudotsuga menziesii*), ponderosa pine (*Pinus ponderosa*), and western larch (*Larix occidentalis*) (Mackie and others 1979; Gruell 1983, in press). The Swan Valley, located north and east of Missoula, Mont. (fig. 1), is representative of this association of deer and conifer forest. Since the mid-1950's however, the upper Swan Valley has been the scene of major timber management activity (roading, cutting, plantation establishment). During the past three decades nearly 50 percent of the white-tailed deer's Swan Valley range has been logged. Timber harvesting has been directed primarily at mature seral forest types.

It is expected that within the next few decades there will be a complete conversion to harvesting of managed second-growth forests. Concurrent with this timber management activity has been the development of other parts of the deer range for rural or recreation subdivisions. In just the past 10 years, we have witnessed an increased public demand for wildlife habitat improvement, expansion of recreation opportunities, as well as safeguarding the valley's watershed values. These demands have led to conflicts among management groups.

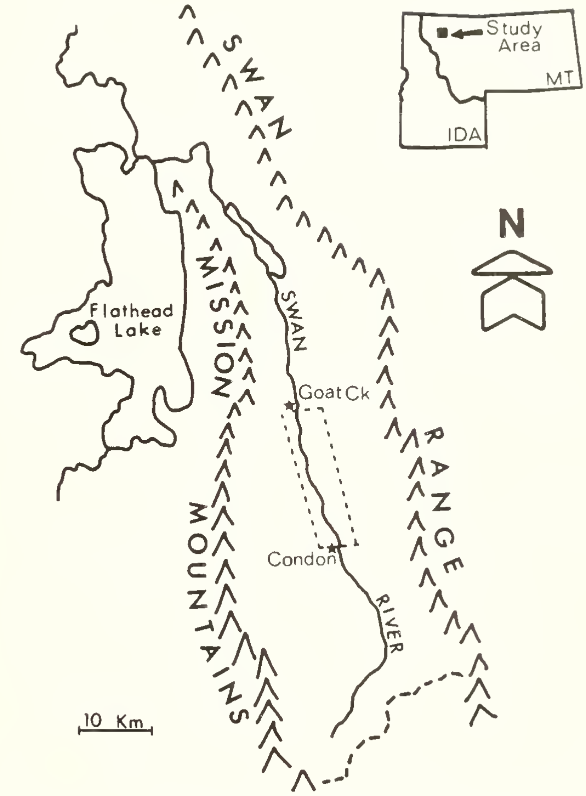

Figure 1.--Location of the upper Swan Valley white-tailed deer winter range in northwestern Montana. Dashed line outlines the approximate location. Southern Mission Mountains are depicted taller than those farther north.

Our contribution to this fire and wildlife symposium focuses upon the results of a recent investigation of the Swan Valley winter deer range (Freedman 1983). Understanding the historical role of fire in the Swan Valley winter deer range was an initial study objective, similar to the study undertaken by Hawkes (1983) in western Canada. Historical information about deer numbers and their distributions, we discovered, is nearly nonexistent. Early reports and assessments made by wildlife biologists suggest that white-tailed deer have been common residents on the upper Swan Valley landscape for a long time and were probably hunted annually by Indians for centuries before Europeans arrived. Deer numbers are believed to have peaked between 1900 and 1915 and again during the 1950's (Bergeson 1943; Weckwerth 1958).

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Mundinger's recent (1982) field studies on this range encompassed deer distribution patterns, habitat and food use, and population dynamics. He found that winter deer use is concentrated within riparian forest types and that more dispersed use occurs within the upland forests. Mundinger determined that deer generally avoided the clearcuts and open-canopied young forests; he concluded that the white-tailed deer population in the Swan Valley is basically controlled by the amount of suitable winter deer habitat. His interpretations suggest that the deer are specifically adapted to and dependent upon the valley's mature, subclimax forest (late seral) and, furthermore, that a relatively stable deer population density is a consequence of that adaptation and dependency. Mundinger believes that the winter range in the valley has been reduced in quality and quantity due to the loss of thermal and concealment cover, to reductions in available winter forage, and to the spatial segmentation and isolation of the critical riparian winter habitats. Modern logging and widespread fire exclusion have altered the winter range, characterized by an overall change in habitat diversity.

Wildfire has been an important ecological influence in the Northern Rocky Mountains for thousands of years (Habeck and Mutch 1973; Arno 1980; Barrett and Arno 1982; Gruell 1983, in press). Early reports (especially Ayres 1900) and an abundance of field evidence indicate that wildfire was commonplace in the Swan Valley. Fire-scarred ponderosa pines, charcoal in the soil layers, and the occurrence of even-aged stands of lodgepole pine (*Pinus contorta*) on parts of the range attest to the past presence of fire; the relative scarcity of old-growth climax forests provides further insight into the influence of historic fire.

Before the introduction of effective fire suppression in western Montana in the 1930's, recurrent wildfires maintained much of the lower forest zones in a complex, mosaic pattern of developmental stages of succession. Gruell (in press) has provided a detailed photographic analysis of western vegetation types and has determined that fires did maintain mosaics of young and mature seral types; fires thinned the forests and produced gaps in the canopies. Fire's influence is likely to have been repetitive and predictable, leading to a degree of stability in range habitat components. We believe the best interpretation of the Swan Valley white-tailed deer population dynamics encompasses the view that long-term stability (steady state) in deer numbers is geared toward the effective exploitation of a relatively stable physical habitat maintained, in this case, by periodic fire disturbances. This important concept, developed by Loucks in 1970, is similar to the ideas expressed by Bormann and Likens (1979). Both view ecosystem stability as equivalent to a shifting mosaic steady state. Schoen and others (1982) and Wallmo and Schoen (1980) have translated these ecologic concepts into recommendations for timber and wildlife managers. It seems evident to us that a clear understanding of the Swan Valley's fire/forest interactions is essential for the correct interpretation of deer/habitat interrelationships. This understandi requires assessing the influence of modern fire suppression on the deer/timber harvest relationshi

Our objectives in the Swan Valley were to evaluate (1) the impacts of modern fire exclusion on winter range quality; (2) the role of recent timber harvesting on range conditions, including browse production and availability; and (3) the consequences of multiple land ownership on the vegetati comprising the winter range.

DESCRIPTION OF THE WINTER RANGE

The Swan Valley is located in northwestern Montana and extends from the Swan River-Clearwater River Divide north to Swan Lake (fig. 1). The valley is bounded to the west by the Mission Mountains and t the east by the Swan Mountains. The Swan Valley i about 40 mi (66 km) long and ranges from 6 to 10 m (10 to 16 km) wide. Elevations on the valley floo range from 3,000 to 4,000 ft (909 to 1 212 m), whereas the adjacent mountain crests reach heights between 7,000 to 10,200 ft (2 121 to 3 090 m). White-tailed deer can be found throughout the uppe valley area, but the winter range unit, as delineated in our study, is located between Condon and Goat Creek (fig. 1). The multiplicity of land ownerships on the winter range exists as alternate mile-square sections. Some land is federal forest (Flathead National Forest), Swan River State Forest, or Burlington Northern (Plum Creek Timber Co.), and the remainder consists of numerous private tracts.

During the Pleistocene the Swan Valley was completely filled with an ice layer; local mountai glaciers moved into the valley also (Antos and Habeck 1981; John 1970). This glaciation left behind a complex microtopography--wetlands mixed with upland terrain--that strongly influences forest community distribution patterns and, importantly, seasonal deer activity within the valley.

The Swan Valley receives about 30 inches (75 cm) o moisture annually; although in the geographic center of the valley, near Condon, a noticeable rainshadow is expressed due to the high Mission Mountains lying directly to the west of the winter range. The annual precipitation at Condon is not known, but July-August measurements are one-third less than stations located just to the north and south. Drier summers in the vicinity of Condon no doubt influenced wildfire behavior in the past.

During typical winters the snow accumulates to ove 3 ft (1 m); snow cover is usually continuous on th winter range from mid-November to the end of March January is the coldest month in the Swan Valley; average maximum/minimum temperatures at the neares stations, at Swan Lake and Lindbergh Lake, are 31°/14° and 29°/11° F (-0.5°/-10°; -1.6°/-11.7°C, respectively. Midwinter thaws, accompanied by col rains, commonly occur in January and February.

The Swan Valley is predominantly forested, with th exception of the wet meadows and riparian sites.

The winter range is composed of late-stage seral forests comprising several habitat types (h.t.) as classified by Pfister and others (1977). These are as follows:

1. *Picea/Clintonia uniflora* h.t. (PICEA/CLUN): This spruce type occupies the floodplain of the Swan River as well as occurring along the courses of tributary streams and on low terrain surrounding depressions and marshlands. On certain local sites the PICEA/CLUN type is replaced by the cedar type, *Thuja plicata/Clintonia uniflora* h.t. (THPL/CLUN), especially where frost is less severe.

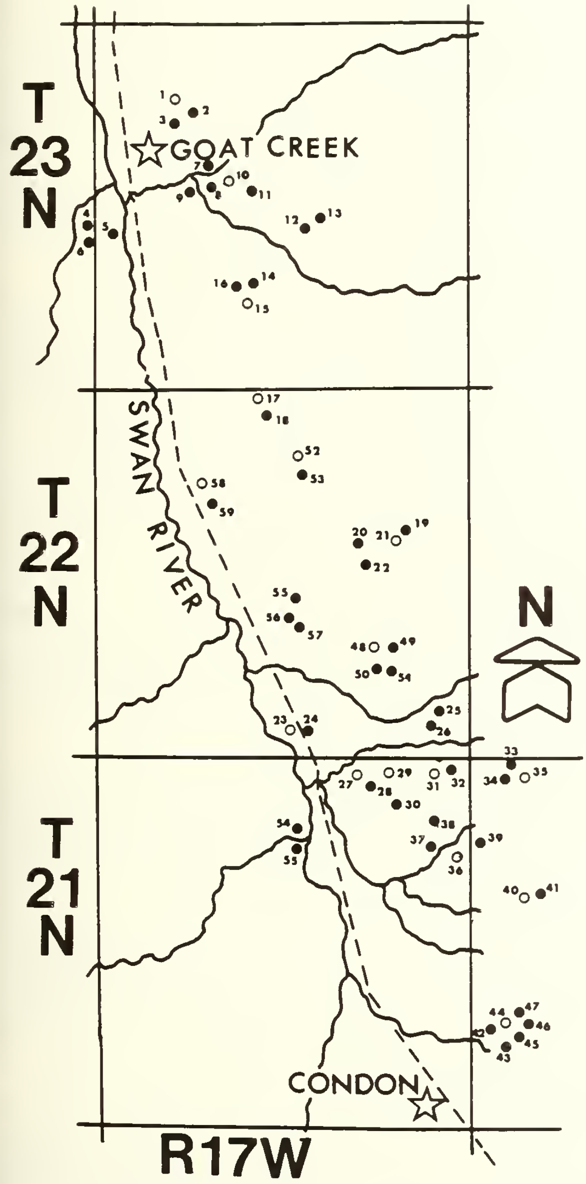


Figure 2.--Swan Valley winter range. Locations are shown of stand samples (solid dots) and stands employed in fire chronology (numbered open circles; see figure 3.)

2. *Abies grandis/Clintonia uniflora* h.t. (ABGR/CLUN): grand fir and subalpine fir types (*Abies lasiocarpa/Clintonia* h.t. [ABLA/CLUN]) occur on the better-drained bottomland terraces and on cool, moist upland sites and/or benches, such as frost pockets and lower north-facing slopes.

3. *Pseudotsuga menziesii/Symphoricarpos albus* h.t. (PSME/SYAL) and (*Pseudotsuga/Vaccinium caespitosum* h.t. (PSME/VACA): the Douglas-fir snowberry and Douglas-fir/dwarf huckleberry types are found on the warmer, well-drained upland slopes, with the former occupying the driest ridgeline sites.

Sapling and pole-sized Douglas-fir, in various combinations with ponderosa pine, western larch, and lodgepole pine, which collectively function as successional dominants, presently occupy the grand fir (ABGR), subalpine fir (ABLA), and Douglas-fir (PSME) habitat type sites. Past fires (Ayres 1900; Antos and Habeck 1981) prevented the expression of the potential climax forests on large portions of the valley's winter range. Wetland forest types and island-like upland forests burned less frequently and likely supported examples of older, later successional stages.

STUDY METHODS

After a reconnaissance of the main parts of the winter range, in an area defined as comprising about 35,200 acres (14 250 ha), a series of 59 stand samples were taken that represent a wide range of the site conditions, habitat types, and silvicultural treatments on the deer range (fig. 2). In each study area a one-tenth acre (about 375 m^2) plot (releve) was positioned to represent the average stand conditions. We employed the paired-stand approach and sampled an untreated or undisturbed stand adjacent to a silviculturally treated stand; both occupied similar physical settings. The field methods follow those described by Pfister and Arno (1980). Tree densities of each plot were recorded by diameter classes (2-inch [5-cm] intervals), and canopy coverages were also assigned to each tree species. Tree age classes were also measured through stem coring. Canopy coverage values were assigned each vascular ground layer plant by sampling twenty 20- by 50-cm quadrats in each releve; physical site features were also recorded. The 59 samples were used in the construction of a polar ordination (Bray and Curtis 1957).

Fire history data were collected from fire-scarred trees searched out in or near each of the sampled stands (fig. 3). The fire history methodology we followed has been described by Arno and Sneck (1977) and by Arno and Peterson (1983). Establishing stand ages by routine increment cores supplemented the fire dates determined from scars.

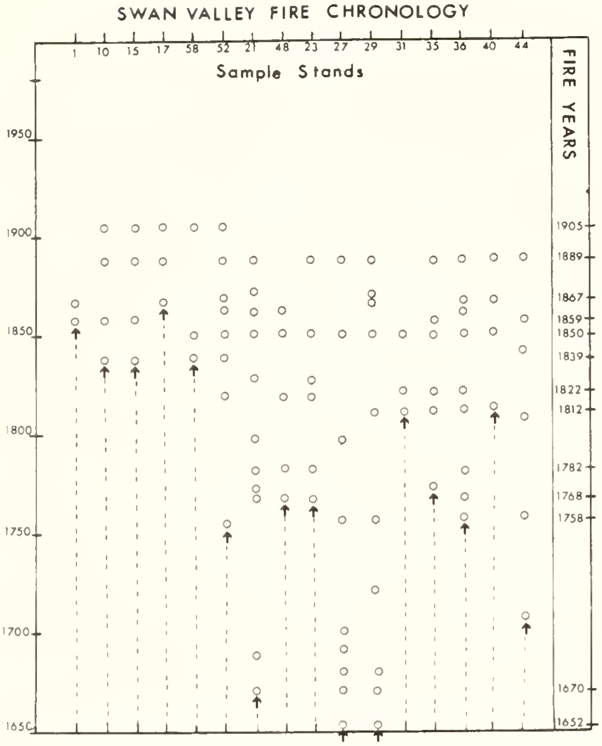


Figure 3.--Swan Valley fire chronology. Each open circle represents the adjusted mean fire-free interval for each stand. The arrow and dashed lines delineate the start of each stand's fire history. The stand arrangement, from left to right, represents a north-to-south geographic gradient (see fig. 2).

The majority of fire-scarred trees encountered were ponderosa pine. Some multiscarred lodgepole pines were also sampled, and their dates of establishment were also used in constructing the fire chronology.

The availability of 1934 aerial photos covering the winter range, as well as current ones, permitted us to analyze winter range changes over a 50-year period. The areas covered with uncut forests, logged/roaded areas, riparian, marsh-shrub, and recent human-made developments were mapped for both sets of photos, and changes in area were determined for each category.

The impact of fire exclusion over the past half century on the compositions of the uncut winter range forests was studied by a detailed diameter/age analysis in an intact PSME/VACA stand. A circular plot, 0.2 acres (0.07 ha), was employed, and the exact positions of all trees in this plot were mapped. Age-diameter relationships were established by coring. Graphical representations of the plot were prepared; a series of plot depictions was prepared, each of a different historical period between 1600 and 1982.

Lastly, the production levels and availabilities of the important winter deer woody browse species were determined, following methods described by Cole (1959) and Lonner (1977); percentage cover values, shrub heights, and degree of hedging were all measured. The distribution and intensity of winter deer use were estimated directly from a series of 1981-82 midwinter cross-country ski trips over the winter range.

RESULTS AND DISCUSSION

Fire History of the Swan Valley

Fortunately for our study a turn-of-the-century descriptive narrative exists, with photos, of this part of western Montana. H. B. Ayres (1900), an employee of the U.S. Geological Survey, was assigned to assess the Lewis and Clark Forest Reserve, which included the upper Swan Valley. He gives special attention to the occurrence of wildfires and their impacts on the timber of the valley. It is worthwhile to summarize some of Ayres' observations and interpretations:

1. At the time of his survey, about 1897, he noted that much of the Swan River Valley was "much burned" with fire-killed timber covering large parts of it. This must have been the results of fires in 1889, a date we have discovered is common in the valley's fire scar record.

2. Ponderosa pine was common in the upper Swan Valley, near Condon, and frequently exhibited fires scars, according to Ayres. We have witnessed this ourselves in the remnant, uncut portions of the winter range.

3. In the Swan Valley, trees, although scarred by fire, still remain abundant, especially in the tributary gulches. Moderate fires, Ayres says, overran the forests, but the treatment merely thinned the forests; tree seedlings are seldom over 10 ft. high.

4. In some forests influenced by light fires tree restocking was so dense it practically formed a conifer "underbrush" layer. In general, Ayres says, underbrush is not dense except in some wetter lower Swan Valley.

5. Some tree cutting, at the time of Ayres' xamination, was for cabin building by rospectors, hunters, trappers, and "squatters." lthough lightning is given credit for ignitions, yres blames most on the carelessness of men, and ere Ayres includes Indians. In 1889, 1,200 mi^2 768,000 acres; 310 931 ha) was burned in the orest Reserve.

6. Ayres states that fires in the area ccurred at all levels of intensity. High-ntensity fires occurred in 1889 as well as forty" years earlier; he is referring to 1850, hen the Swan Valley also experienced extensive ildfire. The more common light fires simply rept along the surface, thinning the forests, and ausing scars ("defects").

7. The low-intensity fires killed lodgepole ines because they lack thick bark; the same ires, observed Ayres, encouraged western larch ominance. This relationship between lodgepole ine, western larch, and other conifers in the wan Valley has been discussed by Antos and Habeck 1981) and Antos and Shearer (1980).

8. As of 1900, Ayres claims that 90 percent f the Swan Valley had been burned over in the receding 100 years, but much of this fire was not f the high-intensity stand-replacement type, since ne burned areas remained forested. Ponderosa pine emains as an overstory dominant, whereas invading ed fir (PSME), larch (LAOC) and spruce (PICEA) are epeatedly killed by fire.

pper Swan Valley Fire Chronology

e must compliment Ayres for being such a keen bserver and interpreter of the early Swan Valley andscape. It helps us greatly in making modern valuations of the past role of fire. The fire istory data we collected were used to construct a aster fire chronology (fig. 3) that spans the eriod between 1650 and the present. Technical ssistance was provided by Stephen Arno and Andrew ilson of the Northern Forest Fire Laboratory Missoula, Mont.). The fire chronology developed ollows the methodology recommended by Arno and eterson (1983). The dates of major fires are nown in this chronology; each stand's fire-free ntervals are identified separately by the open ircles, but a composition chronology is also shown n the right-hand margin. The arrows and dashed ines identify the date when a given stand's fire istory begins.

ne fire-scarred trees in the vicinity of our ample plot were separately inspected and fire ates and intervals determined (see Romme 1982 for efinitions of terms). Next an adjusted mean nterval was derived; occasional missing scar ecovery rings required such adjustments. The evelopment of stand values (fire-free intervals) from two or more trees assumes that fires that are clearly identified on one tree can be counted as a fire event for the entire stand (Arno and Peterson 1983). On open mountain slopes, past fires could run through a stand and miss being registered on some of the trees. In the glaciated upper Swan Valley, the uneven terrain (mosaic of wetlands and uplands) makes it less likely that a given fire, in a typical year, could spread the same way. In years of severe drought all sites might be dry and fires could move unimpeded.

Our Swan Valley fire chronology is based on composite fire scar data that may possess some inherent problems due to the fire-spread differences stated above. Composite fire chronologies do shorten the fire-free intervals. Two ponderosa pine trees, for example, sampled in the vicinity of our plot 27 (fig. 2) comprise the data for this plot sample in the chronology (fig. 3). The fire intervals for each tree, individually, are 47 and 49 years, but since 1693 they have shared only two fire dates out of a possible six. The composite fire-fire interval is less than 30 years. Since the trees are not clumped, but in different microsites near the plot, they could have witnessed different regimes of fire.

The scars record 33 separate fires between 1652 and 1925; figure 3 indicates the major fire years. The pre-fire suppression era predates 1905 (effective exclusion came only after 1930, however) when ignitions were mostly by lightning and Indians (Ayres 1900; Barrett 1980; Davis 1980; Barrett and Arno 1982). After 1905 some organized fire exclusion was initiated; this was the beginning of altered fire frequencies and reduced burned acreage (Gruell in press).

Our fire history analysis indicates that the winter range was burned frequently; in the drier southern half of the range the intervals were shorter than on the more moist northern part. In figure 3 samples 1, 10, 15, 17, 58, and 52 are from the northern part of the range (fig. 2). Between 1758 and 1905 this portion of the range had fire-free intervals of about 30 years, and the presence of western larch and even-aged lodgepole pine suggests the fires here were of higher intensity. The remaining samples are from the southern end of the winter range, and these have a shorter interval of 17 years. It is the latter area that supported the open park-like ponderosa pine forests described and pictured by Ayres (1900). Our data at present do not clearly indicate that the dry habitat types (PSME/SYAL and PSME/VACA) burned more often than the more moist types (ABLA/CLUN, ABGR/CLUN, and PICEA/CLUN), but the geographic position of any of these types within the winter range was indeed important in their burning frequencies.

Other Winter Range Changes

Table 1 summarizes other changes that we were able to document by comparing the 1934 and 1981 aerial photos. Nearly 50 percent of the 35,200 acre (14 250 ha) winter deer range has been structurally modified by logging and attendant activities; much of the change recorded took place between 1955 and 1970, but it continues today. Riparian forests (PICEA/CLUN) and wetland marsh/shrub types have also been reduced in areas by at least 10 percent. The ecological value of these latter types as deer habitat exceeds the percentage of the area they represent. The checkerboard-appearing, alternate-section ownership pattern shows up clearly on the aerial photos. An intricate system of interconnecting access roads evolved to service the various ownerships, and such roading no doubt has also affected the quality of winter deer habitat.

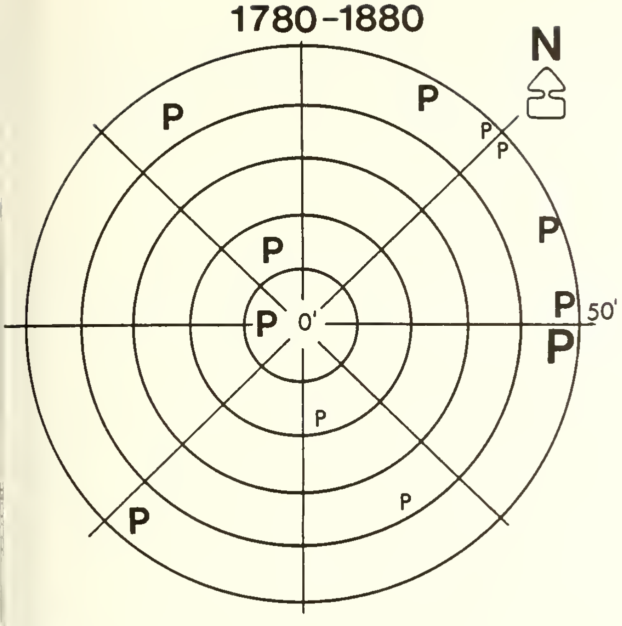
Recent decades have also seen the successful establishment and expanded growth of conifers of all species on the upland forest sites that fires had maintained as savannas. Douglas-fir has been the primary beneficiary of the fire suppression. The historical changes within a single representative PSME/VACA h.t. forest are graphically displayed in figures 4 and 5. The earlier, fire-maintained, open-canopied ponderosa pine (fig. 4, pre-1900) stand rarely included Douglas-fir. In our 1982 census, however, Douglas-fir had gained a strong foothold (fig. 5) and was likely capable of replacing the pine with continued fire exclusion. The Douglas-fir, however, also represent ladder fuels that would remove the ponderosa pine if a fire entered this stand. Similar interpretations have been made by Dieterich (1983) for a mixed conifer forest in Arizona and by Gruell (in press) for other parts of the Northern Rocky Mountains.

Although the occurrence of fire on the winter range has not been completely eliminated, the majority of the fires occurring, from all causes, between 1940

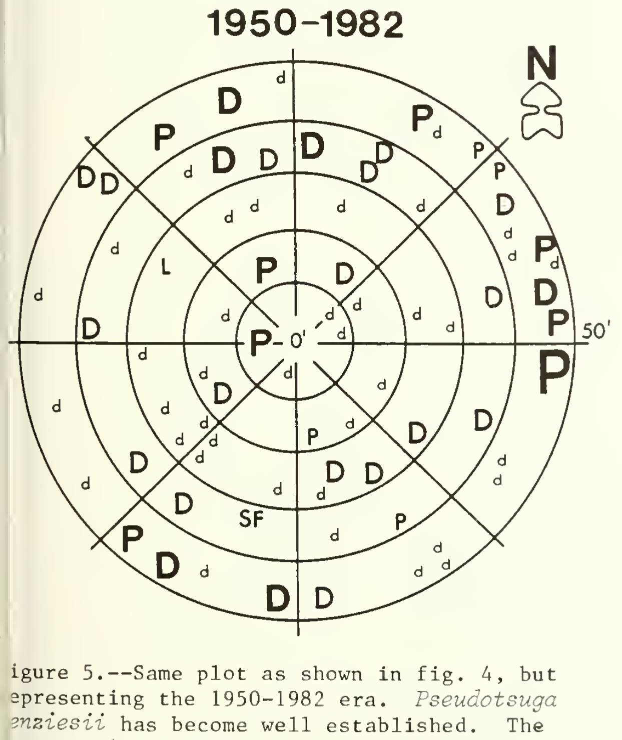
Table 1.--Change in winter range habitat components in the Swan Valley between 1934 and 1981

Winter range Subunits[1]	Year	Acres	Percent of total range
I. Unlogged forests	1934	27,280	77.5
	1981	10,710	30.4
II. Logged forests	1934	40	0.1
	1981	17,360	49.3
III. Riparian/deciduous forests	1934	4,040	11.5
	1981	2,160	6.1
IV. Marshland/shrub types	1934	3,250	9.2
	1981	2,430	6.9
V. Roads, homesites, agriculture	1934	590	1.7
	1981	2,540	7.2
Totals (1981)		35,200	100.0

[1] The areas within each subunit were delineated from aerial photography.



igure 4.--Graphical analysis of a 0.2-acre 0.07-ha) plot in the Swan Valley winter range, as he site existed between 1780 and 1880. A *Pinus onderosa* parklike forest was present. The argest P symbol indicates location of a 40-inch .b.h. pine; the next smaller P's are trees etween 20 and 30 inches d.b.h.; the smallest are ines 15 to 20 inches d.b.h.



igure 5.--Same plot as shown in fig. 4, but epresenting the 1950-1982 era. *Pseudotsuga enziesii* has become well established. The argest D's are Douglas-fir, 6-11 inches d.b.h.; e next smaller D's are 2-5 inches d.b.h.; the ower case d's are seedlings 0-2 inches d.b.h. e L is a 6-inch d.b.h. *Larix occidentalis*, and e SF is a 5-inch d.b.h. *Abies lasiocarpa*. Site s classified as a PSME/VACA h.t. (see text).

to the present have been controlled at Class A (less than 1 acre). The once open-canopied forests, especially those on the southern half of the range, now exhibit increased snow interception as well as increased thermal and hiding cover. They also reveal reduced production of important winter browse species. Fire exclusion and forest succession have altered the pattern of interspersion and diversity of critical deer habitat components. Presently the unlogged upland forests supply needed winter cover, whereas the riparian sites provide much of the essential browse. Many of these changes took place between 1930 and 1955 before large-scale logging was initiated.

Logging Impacts on the Winter Range

Beginning in the mid-1950's, logging entries and other human developments accelerated; these, in a sense, tended to bring about increased landscape diversity but did not replicate the original patterns. The present-day pattern effectively isolates the valuable surviving parts of the winter range from one another.

Large cutting units, ranging up to 1 mi^2 (640 acres; 259 ha) or more, have spatially isolated the riparian components and have generally reduced winter browse availability by removing canopies that previously prevented deep winter snow accumulations. Specific timber harvesting techniques directly influence winter deer movements as well as levels of winter browse utilization. The white-tailed deer prefer serally mature forests that are positioned near the riparian sites. Recent clearcut sites and newly established plantations (under 15 years) were discovered to be only lightly used, if at all, during the period of our study (table 2). The browse species are commonly abundant on most logged sites, but their availability is reduced due to deep snow cover. We estimate that 20 to 40 years of recovery may be needed before significant winter deer use can be expected on such sites. Depending upon site productivity, this is the time required for effective tree canopy to be established. The abundance (percentage cover) of most winter browse species changes on logged sites, but the degree of change depends upon the type of silvicultural system employed. Table 3 compares browse species occurrences in our untreated stands to those in paired treated stands. The data for each species listed must be checked for these interpretations. Some increase following any period of logging, and others respond differently to complete versus partial canopy removal. Table 4 provides data on herbs and grasses in the untreated and treated plots. Many native species show reductions after disturbance, whereas exotics become more common in the logged areas.

Ordination Analysis

Further interpretation of the Swan Valley winter range data was facilitated by the construction of a polar ordination (fig. 6). Much of the compositional variability existing among the 59 samples is

Table 2.--Analysis of Swan Valley winter range[1]

Topographic positions		Upland sites						Riparian sites		
Moisture categories		Dry types (PSME/VACA,PSEM/SYAL)			Mesic types (ABLA/CLUN,ABGR/CLUN)			Mesohydric types (PICEA/CLUN,THPL/CLUN)		
Seral classification		Sapling	Pole	Mature	Sapling	Pole	Mature	Sapling	Pole	Mature
Treated										
A. Logged & burned (clearcut, plantation, seed tree)	Canopy cover	Low	Med	High[2]	Low	Med	High[2]	Low	Med	High[2]
	Browse	High	Med	Low[2]	High	Med	Med[2]	High	High	Med[2]
	Deer use	Low	Med	Med[2]	Low	Med	High[2]	Low	Med	High[2]
B. Logged only (selective)	Canopy cover		Med[2]	High[2]		Med	High[2]		Med	High[2]
	Browse		Low[2]	Low[2]		Med	Low[2]		Med	Med[2]
	Deer use		Low[2]	Med[2]		Med	Med[2]		Med	High[2]
C. Burned only	Canopy cover	Low[2]	Med	High	Low[2]	Med	High	Low[2]	Med	High
	Browse	High[2]	Low	Low	High[2]	Low	Med	High[2]	High	Med
	Deer use	Low[2]	Low	Med	Low[2]	Low	High	Low[2]	High	Extreme
Untreated										
Mature, old growth	Canopy cover			High			High			High
	Browse			Low			Med			Med
	Deer use			Med			High			Extreme

[1] Average canopy cover of tree species (qualitative assessment from coverage class midpoints) average browse (qualitative assessment from availability and productivity of prominent browse species), and overall deer use are summarized according to seral classification and treatment category.

[2] Estimates (not from actual sampling).

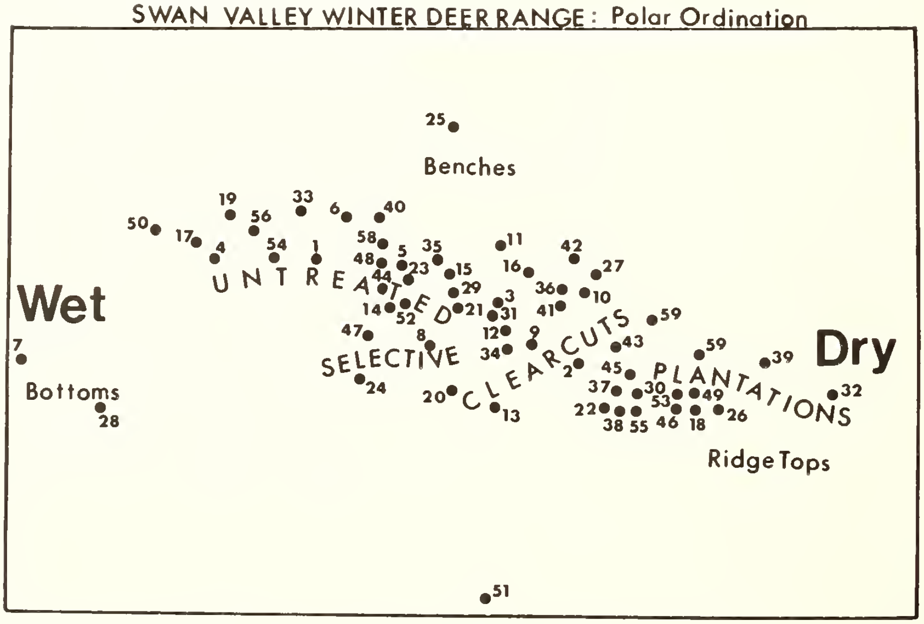


Figure 6.--Polar ordination of the samples taken on the Swan Valley winter deer range. Numbers refer to samples of untreated and treated sites. See text for further explanation.

able 3.--Average canopy cover of major winter range shrub species in the Swan Valley[1]

Species	Percentage cover				
	Untreated (n = 31)	Silviculturally treated			
		Clearcut (n-8)	Plantation (n = 11)	Seed tree (n = 4)	Selection (n = 3)
hrubs:					
Acer glabrum	27	36	15	38	9
Alnus sinuata	63	15	37	--	--
Amelanchier alnifolia	26	39	38	34	9
Ceanothus velutinus	9	20	24	24	--
Holodiscus discolor	8	15	10	--	3
Juniperus communis	6	t[2]	3	15	--
Lonicera cilosa	3	t[2]	t[2]	t[2]	3
Lonicera utahensis	8	6	--	--	--
Pachistima myrsinites	2	3	--	--	5
Rosa gymnocarpa	16	18	12	3	5
Cornus stolonifera	26	--	--	--	15
Rubus ideaus	2	15	12	3	--
Rubus parviflorus	13	15	3	18	15
Salix spp.	8	24	10	15	3
Shepherida canadensis	22	15	38	15	--
Spiraea betulifolia	10	3	3	6	9
Symphoricarpos albus	30	18	38	30	63
Vaccinium caespitosum	12	12	3	10	3
Vaccinium globulare	11	--	--	15	--
ubshrubs:					
Arctostaphylos uva-ursi	23	22	42	50	30
Berberis repens	5	9	3	10	3
Linnaea borealis	16	12	3	10	13

ata are provided for untreated stands and various logged and/or planted stands of occurrence.

t = trace percent cover.

isplayed within this two-dimensional figure. With is ordination, we have identified several interting ecological gradients within the winter nge: site moisture, topographic position, and ilvicultural treatment (fig. 6). Topography and ite moisture are closely linked and stem from the ast influence of glaciation. The untreated ncut) stands occupy the left half of the rdination; the wettest forest type, PICEA/CLUN, curs on the extreme left, whereas the drier, ntreated PSME/VACA stands occupy the central part, ith other mesic types in between. Any of the past-ilvicultural treatments applied to these stands learcut), selection, (plantation) induced compoitional alterations, and these changes cause an dinational shift of the stands to the right, with e clearcut/plantations occupying the extreme ight side of the stand ordering.

e ordination approach allows us to evaluate the gree of community change induced by logging in e various forest habitat types that compose the lley's winter deer range. The moist forest types udied, PICEA/CLUN, ABGR/CLUN and THPL/CLUN, are mpositionally altered to a greater degree than are the drier, upland forest types, such as PSME/VACA and PSME/SYAL. That is, the percentage of compositional dissimilarity between the paired PICEA/CLUN samples (about 70 percent) is greater than between the stand pairs taken from PSME/VACA sites (about 50 percent dissimilar). The cutover moist forests become very brushy, with shrub species residing in low amounts in the untreated stands achieving much higher cover values after canopy removal and other shrubs species entering and becoming well established after the logging treatments. These phytosociological differences were determined from detailed interpretations of the untreated and treated stand pairs within the polar ordination.

Classification of Treated Stands

We developed a classification for the silvicultural treated stands located on the winter deer range. A combination of current cover dominants and successional recovery stage was used to arrive at four different community/structural classes (table 5).

Table 4.--Comparison of forb and graminoid responses in untreated (n = 31) and treated (n = 28) plot pairs sampled on the Swan Valley winter range[1]

Species	Untreated Plots		Treated Plots	
	Presence	Cover	Presence	Cover
		Percent		
Forbs:				
Achillea millefolium	9	2	27	t
Actaea rubra	33	2	12	3
Aralia nudicaulis	15	12	12	19
Arnica latifolia	42	3	19	2
Aster conspicuous	39	1	19	2
Athyrium filix-femina	6	20	-	-
Clintonia uniflora	73	4	46	2
Cornus canadensis	33	4	12	10
Fragaria vesca	76	5	85	4
Galium triflorum	52	6	23	1
Lupinus sericeus	39	2	12	2
Melilotus officinalis	3	t	12	14
Smilacina racemosa	30	4	8	1
Smilacina stellata	42	4	35	2
Streptopus amplexifolius	42	6	12	2
Thalictrum occidentale	55	5	23	1
Trifolium repens	3	3	12	14
Viola orbiculata	45	2	31	2
Xerophyllum tenax	6	t	4	3
Grasses:				
Bromus vulgaris	36	2	46	3
Calamagrostis rubescens	88	18	96	17
Carex geyeri	79	3	92	8
Festuca occidentalis	48	2	62	12

[1] Percentage presence and average percentage cover, based on plots of occurrence, are given t = trace.

Table 5.--Community-structural classification for the silviculturally treated study areas in the Swan Valley winter range[1]

Community/structural category	Treatment type	Associated tree species[2]	Canopy coverage	Browse levels	Winter deer use
Ponderosa pine/sapling	Plantation Clearcut	PICO,PSME, LAOC ABLA, PICEA, ABGR	Low	High	Low
Ponderosa pine/pole	Plantation	PICO, PSEM, LAOC	Medium	Medium	Medium
Douglas-fir/pole	Selection	LAOC, PIPO, PICEA ABGR	Medium	Medium	Medium
Lodgepole pine-larch/ sapling	Clearcut Seed tree	PIPO, PSME, ABLA, PICEA	Low	High	Low
Lodgepole pine-larch/ pole	Clearcut Seed tree	PSME, PIPO, ABGR, ABLA	Low	High	Low

[1] Dominant tree and seral stage are employed in establishing the classes. Levels of canopy cover are based on estimated cover classes; browse assessments are based on field assessments of average availability and productivity; and deer use is based on qualitative assessments taken in winter months and direct field observations.

[2] Listed in order of descending dominance: PICO = *Pinus contorta*; PSME = *Pseudotsuga menziesii*; LAOC = *Larix occidentalis*; ABLA = *Abies lasiocarpa*; ABGR = *Abies grandis*; PICEA = *Picea spp.*

1. The ponderosa pine/sapling type is common n sites that were either clearcut or left for atural regeneration or clearcut and established s plantations. This category often exhibits ight winter deer use. We recorded lodgepole ine, Douglas-fir, and western larch, as well as he climax species in these young forest types.

2. The ponderosa pine/pole type includes tands that do receive moderate levels of winter eer use; overstory canopy is sufficient to rovide cover, and browse is available. stablished ponderosa pine plantations often nclude other seral conifers that have invaded.

3. The Douglas-fir/pole types that have been electively logged support moderate levels of inter deer use.

4. Lodgepole pine/larch/sapling-pole types re derived from stands that were either clearcut r seed-tree cut. These types are dominated ointly by lodgepole pine and western larch, but ouglas-fir, ponderosa pine, and each site's limax species (spruce, grand fir, subalpine fir) re often present in varying amounts. Winter deer se was low in the lodgepole and larch types; rowse is adequate, but insufficient cover exists.

UMMARY AND CONCLUSIONS

he upper Swan Valley winter deer range in western ontana, before modern fire suppression and other ntrusions by Euroamericans, consisted of a complex osaic of successional stages representing a fairly ide assortment of vegetation types. The egetation mosaic provided both summer and winter abitat requirements, but we can only speculate on he details of the original fire-induced forest iversity and the numbers of white-tailed deer it upported. The winter range, furthermore, is set pon a landscape that exhibits a diverse micro-opography developed by Pleistocene glaciation. We elieve that this intricate pattern of diversity as critical to the maintenance of the historical eer populations in this valley.

ur studies suggest that frequent low-intensity ires, before 1930, maintained open savanna-like onderosa pine stands (mature seral), with forb-raminoid understories, on the southern half of the inter range. At the same time, longer interval ire rotations affected the northern third, roducing a greater proportion of western larch ominance as well as even-aged lodgepole pine cover ypes. Although sufficient snow intercept cover thermal/hiding cover) might have been present uring these presuppression times, tall browse pecies may not have been consistently represented n these fire-maintained ecosystems. And these lants likely remained in low abundance and low vailability until the turn of this century. We re in agreement with Wallmo and Schoen (1980) that cologists need to practice greater care in inter-reting deer-fire vegetation relationships and be ite-specific when interpretations are made.

We also believe the 50+ years of fire exclusion, the multiple land ownerships that fragmented the winter range, and the timber harvesting regimes combined to alter white-tailed deer numbers and distributions. Deer numbers likely increased to levels during the fire suppression era (post-1930) exceeding the number present before these landscape changes (that is, browse increased and canopies remained intact). And, as succession continued toward climax, forest development and structural attributes advanced or "succeeded" beyond the ecological optimum for the deer. Before the singular impact of fire suppression could be witnessed and assessed by ecologists, however, the winter range was subjected to the logging entries we have described in this report.

Concerning the modern complexities associated with multiple land ownership and diverse management philosophies, it would be unrealistic to think of managing the upper Swan Valley deer range as a natural area with pristine qualities. Carefully planned, integrated, and implemented silvicultural treatments, however, could closely mimic known natural processes, resulting in a more productive habitat for a relatively stable white-tailed deer population. The white-tailed deer in this part of Montana have adapted themselves to present-day habitat components, best described as a "cultivated" landscape. However, future numbers of deer sustained on this range, maintained as a part of an ecologic steady state, will depend on the timing, type, and intensity of timber harvests, postlogging site treatments, and how we employ our improved understanding of the role of fire, and its absence, in the successional process. None of this will be possible without coordination of future development policies of the multiple land owners.

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BIGHORN SHEEP AND FIRE: SEVEN CASE HISTORIES

James M. Peek, Dennis A. Demarchi, Raymond A. Demarchi, and Donald E. Stucker

ABSTRACT: Responses of seven bighorn sheep populations and habitats to prescribed fire and wildfire in southern British Columbia, Idaho, and Glacier National Park ranged from no influence to increase; interacting factors such as lungworm infection, livestock grazing, and reduction in forage overrode potential benefits of subsequent increases in production and nutritive content of forages. A list of factors to be considered before prescribed fire is used in bighorn habitats is provided.

INTRODUCTION

The purpose of this paper is to summarize investigations of responses of vegetation and bighorn sheep *(Ovis canadensis nelsoni, O. C. californiana)* to wildfire and prescribed burns in British Columbia, Idaho, and Montana. Historical records compiled by Stelfox (1971) and Smith (1954) suggest that, in addition to other habitats, bighorn originally occurred in areas where fires were frequent. Perhaps because of the sensitivity of this species to human influences, direct or indirect (as through livestock grazing), and their frequent association with climax bunchgrass winter range, the prevailing management for bighorn habitat has been to exclude livestock and minimize human activity. In the last decade, a few investigations into fire-bighorn-habitat relationships have occurred, motivated primarily by the low population levels which continued to persist in some areas even after adequate protection of habitat and populations was achieved. Additionally, habitat manipulation to improve forage sources using prescribed fire was becoming more widely recognized as an acceptable practice. Finally, areas of prime bighorn habitat where wildfire was common were being incorporated into wilderness, and a knowledge of bighorn response to fire was needed if fire was to be restored to the ecosystem.

Seven areas have been investigated in the British Columbia-Idaho-Montana region and are reviewed here: Wigwam Flats and the Bull, Chilcotin, and Ashnola River areas in British Columbia; East Fork and Middle Fork Salmon River areas in Idaho; and Glacier National Park, Mont. Each represents a case study comprising different habitats, responses, and implications for management and further research.

ASHNOLA RIVER-EWART CREEK, BRITISH COLUMBIA

Description of Area

The prime California bighorn (*Ovis canadensis californiana*) winter range habitat in the Similkameen River valley has been preempted by orchards, alfalfa fields, livestock grazing, and human settlement. The bighorn winter ranges in the Ashnola River valley can be considered as refuges for a historically much larger population. Two populations exist in the Ashnola: one on the grasslands above Ewart Creek and one on the grasslands of Crater Mountain.

The Ashnola valley is dominated by steep relief, with deeply entrenched valleys. The grasslands are topographically controlled, and few potential grassland sites exist. The existing winter ranges above Ewart Creek are a mixture of bunchgrass communities dominated by *Agropyron spicatum, Festuca idahoensis, Koeleria micrantha, Poa pratensis, or Festuca scabrella*. This area would be considered a high mountain winter range area.

Areas adjacent to the grasslands are dense forests of *Pseudotsuga menziesii, Pinus contorta, or Picea engelmanii*, depending on elevation. Six major fires have occurred in the valley in the past 140 years. The most recent, in the late 1920's, occurred during a period of extreme drought (Harcombe and Kowall 1983).

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ere is only minor encroachment of forests onto rassland soils; the boundary between grassland ils and those associated with forests is istinct, following almost exactly the present ree margins. Present grasslands have remained able for several centuries (Harcombe and Kowall 983).

rning Management Program

e bunchgrass communities have been heavily razed by domestic livestock (cattle, sheep, and rses) in the past and by bighorn sheep and mule er (*Odocoileus hemionus*) (Blood 1961; Demarchi 965). Any effects of fires on the grasslands ve been greatly masked because of heavy grazing.

e British Columbia Fish and Wildlife Branch gional office at Penticton suggests that the art Creek herd of bighorn sheep would benefit if ne designated areas were burned (Hankins 1962); wever, it is doubtful that burning any of those ne areas would increase forage productivity on nter ranges or that burning would create new nter ranges or enlarge existing ones. In dition, burning existing grasslands would cause net nutrient loss due to the poor cation change capacities of these soils (Harcombe and wall 1983).

rning the immature forests and scrublands jacent to the winter ranges could provide gration avenues from winter ranges to summer nges, with some potential spring and fall use nges being created. Several sparsely forested tes are now used as migration corridors, and it doubtful that additional corridors are cessary.

ghorn Response

closed bighorn hunting season from 1909 to 1955 xcept for 1947), a predator control program from 52 to 1955, and the removal of domestic sheep om the summer ranges produced no immediate servable increase in the bighorn numbers (Blood 61). Bighorn numbers did increase, however, by o to two and one-half times in the mid-1960's. ttle were removed from the main Ewart Creek ghorn winter ranges in 1968; as yet the bighorn mbers have not increased over those of the d-1960's.

w plant species changed so as to affect asslands composition in the period 1960 to 1972, though almost all sites visited were in a better ndition class in 1972 than in 1960 or 1963. ghorn sheep distribution and use patterns had anged after the cattle were removed, and one nsequence was that some sites had a lower ndition class after the cattle were removed than der heavy cattle grazing. In total, though, the nter ranges were in better condition 4 years ter the cattle were removed than while they were ill grazing this area.

BULL RIVER, BRITISH COLUMBIA

Description of Area

The Bull River Rocky Mountain bighorn (*Ovis canadensis canadensis*) winter range is located on the glacier terraces and cutbanks of the north side of the Bull River in the Rocky Mountain Trench. This winter range was logged in the 1920's; in July 1931, two large fires burned the logging debris and remaining forests. Once the tree canopy was removed, the high evapotranspiration rate and calcareousness of the limestone-derived soils were able to retard any tree encroachment on to the newly established shrub-grasslands.

Subsequent to the removal of the forest canopy, feral horse numbers increased until an active program by the British Columbia Forest Service was initiated to remove them from all public lands in the East Kootenay. Domestic sheep were permitted on crown range in the 1940's and 1950's but were replaced by cattle. Mule deer, white-tailed deer (*Odocoileus virginianus*), and bighorn sheep numbers increased subsequent to the forest canopy removal and then declined rapidly in the early 1960's during a period of deep snow winters, probably as a result of forage shortages due to too many ungulates on the range.

Burning Management Program

The Bull River winter range was subjected to several decades of overgrazing by domestic and wild ungulates; this caused severe livestock-wildlife interest conflicts. In 1974 this winter range was included in a coordinated wildlife-livestock management plan that allowed for the buildup of forage carryover, control of livestock distribution by herding and drift fences, and the implementation of a controlled burning program.

On April 15 and 16, 1975, the British Columbia Fish and Wildlife Branch and the B.C. Forest Service burned approximately 600 ac (243 ha) of shrub/grass vegetation on moraine, alluvial fans, and lower mountain slopes. On April 5 and 6, 1976, they burned approximately 540 ac (218 ha) of shrub/grass vegetation on glacial terraces and escarpments. The primary vegetation community before these burns was seral shrub-grassland dominated by *Purshia tridentata, Amelanchier alnifolia, Rosa woodsii, Arctostaphylos uva-ursi, Poa pratensis, Poa compressa, Bromus tectorum, Stipa occidentalis, and Antennaria rosea.*

The burning reduced the *P. tridentata* canopy and increased the grass and forb component of the stand. The control of cattle grazing allowed reestablishment of *A. spicatum, F. scabrella,* and *F. idahoensis.*

Population Response

Rocky Mountain bighorn response to the 1931 fires was not documented. An adjacent bighorn population, on the Wildhorse River bighorn winter range that exists on a series of rocky outcrops and escarpments in a dense *P. menziesii/Pinus ponderosa* forest, has about 50 animals. The Bull River area would probably have had the same stand structure before logging in the 1920's as the Wildhorse River has now and was approximately the same size, so there would have been habitat for 40 to 60 animals. By 1964, in spite of the heavy livestock, elk (*Cervus elaphus*), mule deer, and white-tailed deer grazing, there were 250 to 300 bighorn on this winter range. A severe die-off occurred in the winter of 1964-65, affecting all age classes of bighorn; only about 10 animals survived. By 1981 the bighorn population had recovered to about 50 animals.

The bighorn responded to the original logging and forest fire that eliminated the forest canopy by increasing fivefold to sixfold. Animals that had survived a severe die-off caused by overgrazing and deep snows in 1964-65 were able to rebuild the population to 50 from less than 10 once the range condition had been improved by proper livestock distribution and a prescribed burning program. The Bull River bighorn herd appears to have resisted the pneumonia-lungworm epidemic which decimated adjacent herds in the 1981-82 and 1982-83 winters.

CHILCOTIN RIVER-JUNCTION WILDLIFE MANAGEMENT AREA, BRITISH COLUMBIA

Description of Area

The California bighorn (*Ovis canadensis californiana*) that occur along the river breaks of the lower Chilcotin River and breaks off the lower Chilcotin River and adjacent Fraser River (designated as the Junction Wildlife Management Area) are nonmigratory. They exist year-round on dry, low-elevation grasslands, which are composed of few plant species. The climax communities are dominated by *A. spicatum*, *K. micrantha*, and *Artemisia frigida*, whereas seral stands reflecting intense grazing pressure are dominated by *Stipa comata, K. micrantha, A. frigida, and A. rosea* (Demarchi and Mitchell 1973). Some stands of *A. tridentata and A. spicatum* exist at low elevations above the Fraser and Chilcotin Rivers. Some *P. menziesii* forests occur on strong east- and northward-facing slopes, although on the bighorn range few such sites exist.

This area is composed of deep lacustrine silts over deeper fluvial deposits; the rivers are deeply incised and have long grassland slopes interspersed with exposed silt or rock. The Fraser River flows around this land unit, and the Chilcotin, which takes the full force of southerly winds, flows southeasterly into the Fraser River valley.

The grasslands do not show any evidence of being burned; such sign probably has been obliterated by the intense livestock grazing that occurred on this range from the late 1800's to 1973. Adjacent forests are often immature, and the large matriarchal *P. menziesii* show evidence of multiple fire scars--on an adjacent range, Strang and Parminter (1980) suggest that the last large forest fire in the region was before 1926, and that the lack of subsequent fires was due to the removal of litter by grazing.

Burning Management Program

The British Columbia Fish and Wildlife Branch regional office at Williams Lake developed a management plan for the Junction Wildlife Management Area. They recommended prescribed burning as a tool to reduce or retard encroachmen of brush or coniferous species. Prescribed burning was also to be used to rejuvenate the soi and increase grass production (Mitchell and Prediger 1974). Several sites were burned before spring green-up in the period 1975-81. Each area was completely burned.

In 1970 a drift fence was constructed to restrict livestock movement on the main bighorn range, and in 1973 cattle were removed from this area. For several decades before 1973, this area was used t winter-over several hundred steers.

Burning of the *A. tridentata* stands killed off al the *A. tridentata* and most of the *A. frigida*. *Agropyron spicatum* was not affected, and *S. comat* increased on some sites.

Burning of previously overgrazed sites that had been dominated by *S. comata, A. frigida, and C. album* resulted in stands that became dominated by dense swards of *S. comata*.

Bighorn Population Response

Bighorn populations in this range have fluctuated however, most of that information has been lost with time. The area was closed to bighorn huntin from 1918 to 1975. In the 1930's a local rancher complained that placer miners were decimating the bighorns. In 1954, 250 bighorn were counted, and in 1961, the year of the first helicopter survey, 401 animals were observed. Deep snow and extreme cold in the months of December 1968 and January 1969 triggered a decline and in March 1969 only 231 animals were counted (Demarchi and Mitchell 1973). By February 1981 there were over 600 bighorn on this range (Mitchell 1981).

The reduction of cattle grazing from 1969 to 1973 and the full removal of cattle from this range since 1973 have undoubtedly been the major reasons for the improved forage carryover and species composition changes that have been observed in the period 1968 to 1983. The spring burning program, however, may have hampered the recovery of the overgrazed grasslands. These grassland soils have low cation exchange capacities, so it is doubtful burning will help achieve the management objective of releasing soi nutrients for further plant growth (Dick 1980). Any increase in bighorn numbers can be attributed to the termination of abusive livestock grazing, which has subsequently increased forage carryover and improved range conditions.

he burning program does not seem to have had any egative impacts on the bighorn. In fact, they re probably less likely to be discouraged from raversing the narrow bands of forests where the anopy has been opened. There is, however, no orest encroachment onto areas that are considered otential winter range habitat or that are ritical habitats because these sites are ssentially permanent grasslands. The burning of he *A. tridentata* stands may have removed some over that could be used as hiding cover, thermal over (from intense summer heat), a snow nterceptor, and a possible forage source.

IGWAM FLATS, BRITISH COLUMBIA

escription of Area

he Wigwam Flats Rocky Mountain bighorn (*Ovis anadensis canadensis*) winter range is located on large glacial terrace, steep rocky outcrops, and luvial deposits north of the Wigwam River and ast of the Elk River in the Rocky Mountain rench. This unit was not logged before the large ire that burned across it in July 1931. Once the ree canopy was removed, the high vapotranspiration rate combined with the alcareousness of the limestone-derived soils was ble to retard any tree encroachment onto the ewly established shrub-grasslands.

everal attempts were made to homestead this range nit, and it was grazed with domestic sheep, orses, and cattle until the mid-1950's. From 954 to the early 1970's only a few domestic orses grazed this unit. In 1929 the area was esignated as a Hunting Closed Area, and a hunting an was placed on all members of the deer family but not on bighorn sheep). The numbers of elk nd mule deer increased to form large herds until he fall of 1965, when the hunting restrictions ere removed. Bighorn sheep numbers had increased ntil the early 1960's, when a die-off reduced heir numbers to about 200 or 250, or one-half the ormer population.

urning Management Program

his winter range has not been grazed by cattle or several decades; the primary use of the forage esource is for elk, bighorn sheep, and mule deer. he British Columbia Fish and Wildlife Branch has urned some of the seral shrub-grass communities n order to stimulate resprouting of shrubs to enefit the elk and mule deer. Bighorn habitat as been burned in the process. This burning, onducted before spring green-up, has produced ositive responses in the vegetation. In most ites only the standing litter was removed; at ther sites, the shrub growth has been retarded, llowing *A. spicatum* and *F. scabrella* to dominate.

opulation Response

ocky Mountain bighorn response to the 1931 fire s not documented. Judging from the small bighorn populations that occur in adjacent forested habitats and other similar areas, the Wigwam Flats bighorn herd before 1931 was probably less than 200. By 1964, in spite of the homesteading attempts and the heavy elk and mule deer grazing, bighorns numbered about 450 to 500.

An all-age die-off occurred in the winter of 1963-64 and was followed by low lamb production. The population declined to about 200 or 250. With the opening of the range to the hunting of elk and deer, their numbers were severely reduced and the condition of the range improved. By 1970 there were 300 to 350 bighorn on this range, and by 1977 the number had reached 450 to 500. In the winter of 1981-82, however, another die-off and subsequent lamb crop failure occurred, and the bighorn numbers were reduced to 125.

Elimination of the forest canopy through burning has improved the conditions for bighorn sheep on this range. As there is very little forest encroachment on the bighorn winter range at present, fire is not needed to increase winter range habitat for bighorns. There is sufficient bighorn, elk, and mule deer grazing to prevent the forage species from becoming rank. Burning of the seral shrub-grasslands at this time will not further enhance this range for bighorn; however, burning of adjacent areas would be desirable to expand mule deer and elk winter ranges in order to reduce competition with bighorns.

EAST FORK SALMON RIVER, IDAHO

Description of Area

The bighorn winter range on the East Fork of the Salmon River is about 21,200 ac (8 582 ha) of sagebrush-grassland communities and is dominated by *A. tridentata wyomingensis, A. spicatum, F. idahensis, and Poa sandbergi* (Lauer and Peek 1976). This area receives approximately 7 in (18 cm) annual rainfall and is thus among the drier winter ranges occupied by bighorn in this region. The area is high, ranging from about 5,700 to about 8,000 ft (1 744 to 2 438 m) elevation, and is representative of bighorn winter ranges along the Salmon River south of Salmon, Idaho.

Vegetation Response and Utilization

Seven study sites 0.12 to 1.1 acres (0.05 to 0.45 ha) were burned in September 1974 using hand-held propane torches and flares (Peek and others 1979). Each area was completely burned, with unburned stubble height on bluebunch wheatgrass being less than 0.1 in (0.25 cm), and all Wyoming big sagebrush plants burned to ground level. No fall regrowth occurred after burning. Bluebunch wheatgrass declined in production the first year after the fire, then increased the following 2 years. No change in basal diameters of this species after burning were noted. Other grasses were not affected.

Perennial forbs were not affected, except for an increase in production the second year following burning. This was likely related to precipitation patterns. *Lupinus spp.,* and *Crepus acuminata* were the major forbs. Big sagebrush seedlings appeared two growing seasons after the fire.

Heavy utilization by bighorn sheep using these burned areas occurred the following two winters after the fire, with over 66 percent of the plants grazed. Utilization was consistently higher on burned sites than on adjacent unburned sites for 4 years after the fire.

The Bureau of Land Management (BLM) developed a habitat improvement plan for this winter range after these experimental burns suggested that vegetation could be made more palatable to bighorn sheep by using prescribed fire. Drainage heads on this winter range, which are preferred bighorn sheep sites, have received most attention. To date, an estimated 15 to 20 percent or 346 acres (140 ha) of these drainage heads have been treated (Smith 1983). BLM is continuing this program of burning.

Bighorn Sheep Population Response

The bighorn sheep population was estimated at less than 50 animals by Idaho Department of Fish and Game from 1960 to 1970. After this date, the population started to increase, until in 1983, 132 individuals were present (Hickey 1983).

Bighorn sheep populations have thus gone through three fluctuations, ranging from fewer than 50 individuals to over 100 individuals in the 1920 to 1983 period in this area. Causes of these fluctuations are unknown, but the lungworm-pneumonia infection is implicated in the two early crashes (Lauer and Peek 1976). The impetus for the current population increase is not clear. Cattle were removed from critical winter range, and trespass livestock were blocked from access by fencing in 1975, but the degree to which domestic livestock competed for forage with bighorn sheep appeared low, especially on the higher, more rugged areas preferred by bighorn sheep. Human exploitation was consistently low over the period and again would not have been a likely factor influencing sheep population. The burning project conducted by BLM may have been substantial enough to affect bighorn sheep populations, along with the series of milder winters experienced in the region since 1976. At least the burning program must be considered to either have had no effect or a positive effect on this population--certainly not a negative effect. The ultimate test will be if no major die-off occurs again or, if one does, the population crashes to a low which is higher than the previous two lows.

MIDDLE FORK SALMON RIVER, IDAHO

Description of Area

The Middle Fork Salmon River bighorn sheep populations occupy extremely rugged and steep winter ranges dominated by bunchgrass and shrub communities. Sparse stands of *P. ponderosa and P. menziesii* occur in some areas. *A. spicatum and F. idahoensis* are common grasses, and *Balsamorhiza hookeri* is a common forb. Stands of *Cercocarpus ledifolius* occur on the more exposed and rocky sites. The winter ranges extend from 3,280 to 4,920 ft (1 000 to 1 500 m) elevation, whereas summer ranges extend to 9,840 ft (3 000 m) (Smith 1954). Average precipitation is about 12 in (30 cm) annually, with temperatures over 86° F (30° C) in July and August, and less than -2° F (-30° C) in winter having been recorded.

The Ship Island Fire of August 1979 burned 11,000 acres (1 635 ha) from the riverbank to the heads of drainages, encompassing the entire range occupied by one band of bighorn sheep. The area represents typical bighorn sheep habitat for the drainage. The fire was extremely hot.

Vegetation Response

Grasses, including *A. spicatum, Calamagrostis rubescens, and Poa spp.*, were depressed in production, clump diameter, and canopy coverage the year following the burn. *Poa spp. and Bromus tectorum* increased in production the second growing season after the fire.

C. ledifolius was completely burned, with no resprouting or seedling establishment evident for three growing seasons following the fire. *Salix scouleriana and Ceanothus velutinus* seedlings were abundant at higher elevations in *P. menziesii* habitat types the second growing season after the fire. *Glossopetalon nevadense* was determined to be a resprouter and was browsed at approximately twice the level on burned sites as on unburned sites.

The major effects of this fire were a dramatic reduction in forage the winter following the fire and elimination of *C. ledifolius*, an important forage species for these bighorn sheep (Smith 1954).

Bighorn Sheep Population Response

The bighorn sheep population on the Ship Island Burn and immediately adjacent drainages was estimated at approximately 90 animals before the fire (Hickey 1983). Variation in the number following the fire was attributable to weather conditions during the count and differences in winter severity, rather than actual changes in population size. Population parameters of bighorn sheep occupying the Ship Island Burn are similar to those of bighorn sheep immediately across the river and unaffected by the burn.

ighorn sheep did prefer to graze on areas which ad been burned after vegetation had regrown; owever, no major shifts in distribution were pparent, and thus the only discernible response y bighorn sheep was local shifts in habitat use, nitially a shift away from burned areas, and then shift onto the new vegetation.

LACIER NATIONAL PARK, MONTANA

escription of Area

he bighorn sheep winter range of 420 acres (170 a) in the Swiftcurrent Valley, the major winter ange for bighorn sheep in Glacier National Park, as almost completely burned in 1936 (Riggs 1977). his area is a mixture of climax bunchgrass ommunities dominated by *A. spicatum, F. dahoensis, F. scabrella, and Amelanchier lnifolia*, and seral vegetation of subalpine fir abitat types (Pfister and others 1977). The eral communities important to bighorn occurred on icrosites of concave relief which would retain indblown snow in winter; these comprised 26 ercent of the winter range. *Carex geyeri, piraea betulifolia, and Calamagrostis rubescens* ere common species in these seral stands. uccession toward conifers after the 1936 fire was ery slow on this area because of the severe limate of high winds and rapid freezing-thawing onditions in winter. Very little conifer egeneration was apparent 40 years after the fire, llustrating the severity of the climate on these ites. This area would be considered a high ountain winter range with vegetation epresentative of the eastern Rocky Mountain lopes at 4,600 to 6,900 ft. (1 400 to 2 100 m) levation in this region.

egetation Response and Habitat Use Patterns

limax bunchgrass communities occupied 74 percent f the winter range that Riggs (1977) described. is investigations of composition and haracteristics of these communities revealed ittle, if any, effect attributable to the burning 0 years afterward. Nevertheless the seral ommunities previously described did persist over hat period of time and likely will continue to be ecognizable in the near future. These seral ommunities were preferred foraging areas for ighorn sheep when they were snow free in winter. ince succession to conifer vegetation would ikely reduce the forage on these sites, and ighorn sheep generally favor nonconiferous egetation, the tentative conclusion is that the ire added winter range to this area for bighorn heep.

opulation Response

ighorn sheep population response to the 1936 fire as not well documented, but available records ere summarized by Riggs (1977). Population stimates in the 1925-83 period ranged from 40 to 34, with a history of artificial winter feeding, horse grazing on the winter range, and periodic die-offs due to pneumonia among the bighorn sheep. Following the 1936 fire, the population suffered substantial mortality due to lungworm (*Protostrongylus stilesi*)-pneumonia interactive infection and disease. The winter feeding program, which concentrated the bighorn sheep and may have aggravated the die-off, was discontinued after that winter, and the population increased from 30 in 1939, to 40 in 1951, 82 in 1967, and 115 in 1975. Whereas the earlier estimates occurred in winter, the 1975 estimate was taken in May and may reflect better observing conditions and/or a spring influx of bighorn sheep onto this winter range coincident with spring green-up.

Responses of bighorn sheep populations to this burn were obscured by the artificial feeding, grazing, and disease-parasite interactions; however, population estimates before the burn ranged from 40 to 134 and, after the burn, 30 to 115. On this basis, the conclusion is that no appreciable response to vegetation change attributable to this fire occurred.

It is noteworthy that no die-offs due to the lungworm-pneumonia complex have been observed in this area since the winter following the burn. This does not mean that die-offs have not occurred or will not in the future or that the additional range provided by the fire is related. It does however, bring up the possibility that the population, which appears to have been at the same level before and after the fire, may not be as concentrated on habitats now as before. If so, this postulated broader dispersal pattern of sheep across this winter range may be related to the absence of a die-off since the fire and thus is a relationship worthy of further investigation.

DISCUSSION

The areas considered here encompass the broad range of habitats occupied by bighorn sheep in this region. Some were forested sites that were changed to shrub/grass ranges by wildfires in the early part of the century. Other sites were native grasslands or shrub-steppe that may have burned periodically. Plant succession following burning varied extensively, from rapid restoration of preburn conditions to extremely slow changes where conifer cover was removed. A variety of responses in vegetation and bighorn sheep were evident. The British Columbia experience illustrated that once the initial bighorn sheep range is created, additional burning may not benefit bighorn sheep if subsequent livestock grazing is intensive enough to affect forage species used by bighorn sheep. The lungworm-pneumonia complex, if prevalent, may limit capabilities of bighorn sheep to respond to increases in forage quantity and/or quality resulting from burning. In areas of high fire frequency where plant responses are short-lived, the bighorn sheep response may also be short-lived or nonexistent.

Positive results from burning these areas range from changes in bighorn sheep distribution (which may have reduced the effects of lungworm infection), to stabilization of populations, to increases. In all cases, however, definite proof that burning was responsible is lacking because we are unable to isolate the effect of the fire from other potential limiting factors. The increase of bighorn sheep in the East Fork Salmon River area may be the exception, since the only factor that appeared to have changed over the period that was considered to be affecting the sheep population was the prescribed burning program.

At least four important factors can be considered to potentially limit these populations, including lungworm; poor range conditions due to past livestock use; low range productivity (due to drought, lack of grazing, or poor soils); and competition with other big game. All of these may be predisposed by severe weather. Additionally, predation is a possible limiting mechanism.

These case histories illustrate that prescribed fire will not necessarily increase bighorn sheep populations and may have a negative effect. The benefits of increasing forage production may be outweighed by other limiting factors. Nevertheless, there is evidence that use of prescribed fire reduces incidence of lungworm infections, and this should be evaluated further in populations with a history of chronic lungworm problems. There is also evidence that prescribed fire, used in conjunction with controlled grazing plans, may benefit bighorn sheep. In areas of high fire frequency where fire management policies will allow fires to burn, the effect on bighorn sheep should be minimal.

Prescribed fire is a useful tool in managing bighorn sheep habitat if a proper plan which identifies objectives and considers the limiting factors is developed, and the burning follows the prescription.

Fire can negatively affect bighorn sheep habitat when range condition is poor and forage species cannot respond, when nonresprouting species which provide important forage for bighorn sheep are eliminated, or when too much area is burned and inadequate forage remains until the next growing season. Another potential negative response is observed when other species, especially elk, are attracted to prescribed fires intended to benefit bighorn sheep. When fires produce these negative results, bighorn sheep then become more vulnerable to the other limiting factors. Therefore, a well-thought-out plan must be developed before fire is considered for use on bighorn sheep range. Plans must consider the following:

1. Condition of plants. Plants to be favored should be in robust condition to respond most satisfactorily to burning. This also means that timing of the burn and intensity of the burn must be considered.

2. Plant response. Are species that burn intended to resprout, reseed, or increase in productivity from unburned residual growth? Areas where nonresprouting species occur and which serve as forage at critical times should be given special attention. If objectives are to rejuvenate deteriorated stands, fire may still be considered a part of the treatment. If nonresprouting stands are productive, then efforts to restrict fire from these areas may be needed.

3. Adjacent conifers. The possibility of creating more open range that is favored by bighorn sheep exists if conifer stands, or tall shrub fields, occur next to currently used range. Bighorn sheep may colonize adjacent habitats as rapidly as commonly associated big game species like elk or mule deer.

4. Limiting factors. Factors that may limit bighorn sheep populations should be identified, and the effect of burning habitats on these limiting factors should be evaluated. Care should be taken since limiting factors are interactive.

    a. Lungworm. Lungworm infections can possibly be altered by reducing bighorn sheep concentrations; however, if burns are small and concentrate bighorn sheep, results could be negative. If burns disperse populations, the effects could be positive.

    b. Competitive. Burns may attract elk or deer to the ranges used by bighorn sheep, which may result in competition for forage.

5. Bighorn sheep response. Changes in distribution patterns may be a sufficient goal if the objective is to reduce lungworm infection. If population maintenance or increase is the goal, then larger burns will be needed. Provision for adequate forage remaining after the fire needs to be considered.

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RANGE BURNING, STONE'S SHEEP, AND

THE LEAKY BUCKET

Dale R. Seip and Fred L. Bunnell

ABSTRACT: Stone's sheep (*Ovis dalli stonei*) in northern British Columbia used subalpine, burned ranges at certain times of the year. In the spring, burned ranges did not appear to provide more nutritious forage or a greater intake rate for sheep than did unburned ranges despite much greater herbage production on burned slopes. The abundant forage on burned ranges did provide superior winter range when available; however, most burns were unavailable to sheep in a severe winter due to deep snow accumulation. Therefore, although burned ranges produced much more forage than unburned ranges, this forage generally was not available at the time of the year when forage was limiting.

INTRODUCTION

Stone's sheep (*Ovis dalli stonei*) and elk (*Cervus canadensis*) in northern British Columbia often use subalpine grassland slopes that occur in areas where the spruce forest has been burned by natural or human-caused fires. This observation has led to a widespread burning program directed toward improving wildlife habitat by creating more subalpine grasslands. The value of such a program; however, is based on an assumed relationship between habitat use and need. The same assumption is the basis of a wide range of other wildlife-habitat management programs. In this paper we examine the validity of the assumption using examples from our research on range burning and Stone's sheep.

The law of limiting factors states that if an organism is dependent on several environmental factors, the one closest to the minimal requirement for survival will be the limiting factor (Blackman 1905). The analogy of a leaky bucket with a series of holes in the sides demonstrates this concept. In this case, the lowest hole will determine the water level and plugging the uppermost holes will have no effect until the lowest hole is plugged. Similarly, increasing some necessary environmental factor fo an organism will not be effective if some other factor is limiting. Although this principle does not always strictly apply because some factors ma have synergistic effects with the limiting factor the general principle remains valid. Thus an increase in a particular habitat type will not benefit a wildlife population if that habitat is not limiting, even if the animals extensively use the habitat. Our objective was to determine if range burning eliminated or alleviated a limiting factor and thereby benefited Stone's sheep populations.

STUDY AREA AND METHODS

The study was conducted in the northern Rocky Mountains in the vicinity of Toad River, B.C. (59°N, 125°W). We studied about 100 Stone's shee living in an area about 350 mi^2 (900 km^2) of whic about 75 mi^2 had been burned regularly at an average interval of about 9 years for the past 80 years (fire history analysis by J. Parminter). These animals were compared to a population of 12 to 150 sheep in another area about 300 mi^2 (780 km^2) that had not experienced fires for at least 125 years except for one small 2-mi^2 (5 km^2) burn that occurred 3 years before the study. During the study, about 20 to 30 percent of the burned slopes were reburned each spring by local residents attempting to increase forage production.

Herbage quantity was measured by clipping all the plant material in 2.7 ft^2 (0.25 m^2) plots and sorting the material into live graminoids, live forbs, and dead vegetation. This material was ai dried, weighed, and the value multiplied by a correction factor of 0.92 to convert it to oven-dry weight (Seip 1983). Tiller length of grasses was measured from the ground to the tip o the longest leaf of randomly selected tillers. Forage samples were analysed for crude protein an acid detergent fiber (ADF). Fecal samples were collected and analysed for crude protein and lungworm larvae (*Protostrongulus spp.*). Lungworm counts were conducted by Dr. W. Samuel, Departmen of Zoology, University of Alberta. The other laboratory analyses were done by the Wildlife Habitat Laboratory, Washington State University, Pullman, Wash.

Foraging time was determined during dawn to dusk observations during which the behavior of each sheep was recorded at 5-minute intervals. Biting

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rate was determined by counting the number of bites taken by adult ewes during repeated 1- to 2-minute foraging periods. The study area and methods are described in detail in Seip (1983).

RESULTS AND DISCUSSION

Stone's sheep on the burned range extensively used fire-induced subalpine grasslands in the spring and to a lesser degree in the fall. These grasslands were dominated by ryegrass (*Elymus innovatus*) and mixed forbs. In winter, some sheep used burned slopes, but most sheep used windswept alpine ridges because deep snow prevented the use of most burned, subalpine slopes. Do Stone's sheep benefit from being able to use subalpine grasslands created by range burning? That is, are burned ranges a limiting resource?

Spring Range

Sheep without access to burns in spring used natural subalpine clearings such as rockslides and avalanche chutes instead. These natural clearings were dominated by bearberry (*Arctostaphylos uva-ursi*) cover and supported only sparse grass production. Graminoid production on burned ranges was about six times greater than production on natural, subalpine clearings in May (table 1). Stone's sheep fed primarily on grasses during the spring (Seip 1983); however, one cannot simply conclude that because sheep eat grass the range with greater grass production was superior.

The quantity of forage can be limiting if: 1) the total production is inadequate to meet the needs of the population or, 2) the forage distribution is too sparse to allow the animals to obtain an adequate intake rate of high-quality forage.

Spring ranges showed no evidence of heavy grazing pressure. The grass production on both burned and unburned ranges greatly exceeded the requirements of the sheep using these ranges. Alternatively, the sparse forage on unburned spring ranges potentially could have been inadequate to provide an adequate intake rate. Intake rate of sheep is primarily determined by the bite size that they can obtain and is independent of grass tiller density (Allden and Whittaker 1970). Bite size is primarily determined by the grass tiller length. The grass tiller length on unburned spring ranges was the same as on burned ranges (table 1). The lower grass biomass on unburned ranges was the result of a much lower tiller density; therefore sheep probably were able to obtain the same bite size on both ranges. The biting rate was also the same on both range types (table 1) despite the difference in tiller density. Thus, it appeared that the same intake rate could be attained on both range types. This conclusion was supported by the observation that the daily foraging time of the sheep was the same on both range types (table 1). If the sheep on unburned range had a lower intake rate, they would be expected to compensate by increasing their foraging time (Allden and Whittaker 1970; Arnold 1975).

Forage quality (crude protein, ADF) did not differ between burned ranges and natural subalpine clearings (table 1). The quality of food eaten by the sheep, as indicated by fecal protein levels, was also similar between range types in May (table 1), although it began to increase about 7 days earlier on burned range (Seip 1983). Food habits of the sheep were almost identical on the

Table 1.--Comparison of range characteristics and foraging behavior of Stone's sheep on burned and unburned ranges in northern British Columbia during mid-May

Item	Burned subalpine grassland	Natural subalpine clearings
Graminoid biomas	107 lb/acre (120 kg/ha)	17.8 lb/acre (20 kg/ha)
Tiller length	3.9 in (10.0 cm)	4.0 in (10.2 cm)
Tiller density	150 tillers/yd^2	25 tillers/yd^2
Graminoid quality		
Crude protein (%)	18.4	18.5
ADF (%)	28.6	26.1
Percent fecal protein (X±SE)	13.7±0.36	13.4±0.76
Percentage of daylight spent foraging		
Ewes	61-64	63
Rams	49-58	57
Bites/minute (X±SE)	34.2±1.5	34.8±2.6

different spring range types (Seip 1983). Horn growth of yearling rams was significantly greater on burned ranges (Elliot 1978; Seip 1983), but it was not clear if this was a function of superior spring range. Overall, it appeared that burned ranges were not superior to unburned ranges in spring because the forage available on unburned ranges was just as nutritious and forage quantity was not limiting the intake rate. Providing more spring forage by range burning would be like plugging up holes too high in the leaky bucket.

Summer Range

In the summer, Stone's sheep used high alpine ranges where forage quality was superior to that available on subalpine ranges (Seip 1983) and so the availability of subalpine, burned ranges was of no consequence at this time of the year.

Winter Range

When winter arrived, most sheep used windswept alpine ridges, but some sheep used fire-induced, subalpine grasslands. It was necessary to determine whether winter ranges were a limiting factor. Under conditions of high snowfall, Stone's sheep became restricted to small areas of the total range. Sheep did not use areas where the snow depth exceeded 12 inches (30 cm). Grazing pressure in these areas was heavy, and essentially all of the available forage was consumed on both alpine and burned, subalpine winter ranges. Less than 0.03 oz/yd^2 (1 g/m^2) remained in those areas of low snowfall that were heavily used in a severe winter. Burned, subalpine winter range produced much more forage than did the alpine range; this meant more food per sheep was available on the burned, subalpine winter range (table 2). The greater forage production on subalpine range was reflected by higher lamb production following the severe winter and lower lungworm larvae (*Protostrongulus spp.*) counts than for sheep wintering in the alpine (table 2). Therefore, winter forage appeared to be a limiting factor.

Even in areas with extensive burned slopes and abundant herbage production, however, most of the range was unavailable when the slopes became covered in deep snow. Thus it was not burned slopes that were limiting but windswept slopes that provided "available" winter forage. Creating more burned range, which is not available in severe winters, would be of no use. At present there are extensive areas of burned grassland that produced large amounts of forage, but usually these areas were unavailable in winter and most of the sheep were forced to retreat to windswept alpine peaks. Burning programs to enhance Stone's sheep range should be directed toward burning areas that will be windswept and remain snow-free in severe winters. Unfortunately, such areas appear to be rare. In the extensive subalpine areas that had previously been burned, few areas were used by Stone's sheep in winter. It may not be possible to increase the area of Stone's sheep winter ranges much beyond that already provided by windswept alpine areas.

A similar situation may be occurring with elk in the area. Elk used burned, subalpine slopes for most of the year, and the population has increased in response to the burning program. For most of the year, forage was superabundant on the ranges used by elk; however, in the severe winter during the study most of the range was also unavailable to elk due to deep snow. In this situation it is unlikely that more burning in the area would benefit elk despite the fact that burning initially created habitat for elk. In fact, too much burning could be detrimental because elk may need forested areas for cover or to provide browse in winter. Other studies have found that elk feed heavily on browse when grasses become unavailable due to snow (Janz 1983; Singer 1979).

CONCLUSIONS

The observation that animals use a particular habitat type does not necessarily mean that the animals need that habitat. The population will not necessarily increase if availability of that habitat is increased or decline if the habitat is

Table 2.--Herbage production, lamb production, and lungworm counts on two different winter ranges during a severe winter

Item	Burned subalpine	Alpine
Herbage production	984 lb/acre (1,100 kg/ha)	<90 lb/acre (100 kg/ha)
Forage availability (kg/sheep)	206	<100
Lambs/100 ewes produced the following spring	35	26
Lungworm larvae/g feces[1]	38	417

[1] *Protostrongylus spp.*

duced. Rather, one must determine if the bitat type is a limiting factor. There are two iteria, either of which would justify the nclusion that a range is limiting:

1. The resources provided by that habitat e reduced in a density-dependent fashion by mpetition between the animals, resulting in gative feedback on the population.

ternatively, even if the resources in a certain bitat type are not reduced by competition, imals that have access to that habitat type may better off than animals that do not have access that habitat type. In this situation, one must monstrate that:

2. Animals with access to the different bitat type are in better condition and/or have a gher population growth rate than animals without cess to that habitat.

this case, once the animals do have access to e superior habitat type, providing more of that bitat type will not be beneficial until the sources become limited by density-dependent mpetition.

the case of Stone's sheep, winter forage was ogressively reduced by density-dependent mpetition resulting in reduced productivity and orer physical condition, thus satisfying the rst criterion. Providing more available winter nge should benefit Stone's sheep. That task is de difficult, however, by the fact that ailable winter range is largely a function of ow accumulation, which is difficult to nipulate.

spring, there was no evidence that the forage either burned or unburned ranges was gnificantly reduced by grazing; thus the first miting factor criterion was not satisfied. ternatively, if burned ranges provided superior trition compared to unburned ranges, sheep pulations could potentially benefit from access burned ranges, thus satisfying the second iterion. Burned ranges, however, did not appear provide superior nutrition because intake rate d forage quality were similar on both range pes. Even if burned ranges were superior to burned ranges in spring, even small burns would adequate to meet the requirements of the imals because of the high forage production on rned slopes. Widespread burning would be perfluous once the animals had access to burns. re burning would be justified only when the sources became limited by density-dependent mpetition.

erall, the value of range burning to enhance one's sheep range was limited because it did not pear to provide superior spring range and, though winter range was limited, most burned, balpine ranges were not available in severe nters due to snow.

A final consideration is that habitat which currently does not meet the criteria for being a limiting resource may become limiting in the future under different environmental conditions or under conditions in which some other limiting factor is plugged up and the population level increases to a new hole in the bucket.

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FIRE ECOLOGY OF ANTELOPE BITTERBRUSH IN THE NORTHERN ROCKY MOUNTAINS

Stephen C. Bunting, Leon F. Neuenschwander,
and George E. Gruell

ABSTRACT: Frequency of resprouting and number of newly established seedlings of antelope bitterbrush were sampled on sites burned by prescribed burns and wildfires 3 to 10 years previously to determine the effect of habitat type, growth form, and season of the burn on bitterbrush. Significant differences in resprouting response occurred among the growth forms, season of burning, and habitat type. Seedling establishment was also markedly influenced by growth form, season of burning, and habitat type. Results of this study document the short-term effects of fire on bitterbrush populations in the Northern Rocky Mountains.

INTRODUCTION

Antelope bitterbrush (*Purshia tridentata*) is widely distributed on vast areas of western North America. It is a major component in the diet of big game animals in many areas (Guinta and others 1973; Kufeld and others 1978) and may be used seasonally by domestic livestock (Cook 1954; Julander 1955). Because bitterbrush is important as a forage species, it is a major consideration when planning management practices on range vegetation.

Reviews of bitterbrush literature have been written by Basile (1967) and Clark and Britton (1979). Literature regarding the effects of fire has also been summarized in recent publications (Martin and Driver 1983; Rice 1983); however, the reported response of bitterbrush to fire varies considerably. Hormay (1943) and Billings (1952) stated that bitterbrush sprouted rarely and was nearly eradicated by fire in California and the Great Basin. Others have reported low sprouting potential for the species (Nord 1965; Daubenmire 1970; Sherman and Chilcote 1972). In eastern Idaho, the resprouting ability has varied from moderate (Blaisdell 1953) to high (Pechanec and others 1965).

The variation in resprouting is due to a number of factors. The growth form of bitterbrush ranges from low decumbent individuals to upright columna forms (Nord 1965) and has been reported to be related to resprouting potential. Decumbent form have been reported to resprout more readily than the columnar forms (Wright and others 1978; Clark and others 1982). The season of the fire may als affect the ability of plants to resprout. Most research indicates that sprouting is greatest on spring fires and least on summer burns. Sproutin response of bitterbrush burned in the fall is intermediate (Blaisdell and Mueggler 1956; Clark and others 1982; Murray 1983). The effect of season of burning may be confounded with several other factors. Soil moisture is often highest in the spring and lowest in the summer. Clark and others (1982), however, could not show a significant effect of soil moisture by artificially watering bitterbrush plants before burning. The carbohydrate recharge pattern may also be a facto Carbohydrate levels are lowest in midsummer after seed set and do not recover until late summer (Menke and Trlica 1981). Late summer corresponds to the time when bitterbrush is most susceptible fire.

Fire severity varies seasonally and may affect resprouting ability. In most regions, low-severi fires often occur during late winter and spring. Highest severity fires would likely occur during the summer period. Studies have shown an inverse relationship between resprouting and fire severit (Blaisdell 1950, 1953; Blaisdell and Mueggler 195 Murray 1983). Driscoll (1963), however, found little correlation with fire severity and indicat that the soil surface texture was a more importan factor in central Oregon.

Murray (1983) concluded that bitterbrush annual production on burned sagebrush grass ranges in eastern Idaho was less than on unburned areas aft 30 years; however, bitterbrush studies in foreste communities have found increased production after fire even though plant density may decrease (Edgerton and others 1975; Stuth and Winward 1976

Seedlings are the primary mechanism involved in t development of a new stand of bitterbrush followi fire (Daubenmire and Daubenmire 1968; West 1968), and seedling establishment has been as variable following fire as resprouting. Blaisdell (1950) reported that seedling establishment varied inversely with fire intensity (severity). Sherma and Chilcote (1972) stated that rodent caches wer important sources of seed reproduction and that rodents preferred to cache seeds in areas where t duff and litter were removed. Driver and others (1980) reported better reproduction from seed in

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orested areas with the most severe fires. Some of his variation may depend on the microclimatic onditions of the site. In the more xeric sage-rush-grassland sites, adequate microsites for eedlings may be present following a low-severity ire. The remaining vegetation may be important to odify the microclimate; however, in more mesic orested sites, a more severe fire may open up the ense vegetation and provide suitable microsites or seedling establishment. Dealy (1970) and ubbard (1956) found the release from competition y other plants a major factor in the establishment f bitterbrush seedlings. Ferguson and Medin 1983) found few bitterbrush seedlings on an area rotected from livestock grazing and fire.

roduction of bitterbrush seed varies annually, and ood seed crops occur infrequently (Giunta and thers 1978). Rodents are important in the dissemi-ation and planting of seeds, and a high proportion f seedlings results from germination of seeds in nutilized rodent caches (Hormay 1943; Nord 1965; est 1968; Sherman and Chilcote 1972). Rodents ransport seeds up to 1,000 ft (305 m) (Nord 1965) nd are important in the movement of the relatively arge bitterbrush seed away from parent plants. odents, however, may also reduce bitterbrush eproduction by consuming large quantities of the nnual seed crop and by eating developing seedlings Hubbard and McKeever 1961).

ETHODS

his study was conducted in the Northern Rocky ountains, primarily in Idaho and Montana. Within his region 56 prescribed burn and wildfire sites ere located (fig. 1). These represent variation hat occurs in habitat type, season of fire, growth orm, and fire severity. Only burned sites between and 10 years old were sampled. A minimum of years was chosen because many plants that nitially resprout following a fire die in ucceeding years (Clark and others 1982). We elieve that those individuals that lived for years had a high probability of survival. The pper limit was chosen because our experience has hown that after 10 years the skeletons of the urned bitterbrush plants begin to decompose, thus aking it difficult to establish the prefire ensity. Also, after 10 years, the sprouts become eproductively mature and begin to contribute to he seed source on the burn. Consequently, it ould become increasingly difficult to determine he immediate postfire density of seedlings.

n each burn, one sample site was randomly selected rom those where the prefire density of mature itterbrush was estimated to exceed 200/acre 500/ha). Five 6.56- by 164-ft (2- by 50-m) belt ransects were located by using a random numbers able. The density of dead, resprouting, and nburned plants on site at the time of the fire was ecorded. Seedling density was also recorded for ach transect. Additional data collected included abitat type, bitterbrush growth form, season of ire, elevation, slope, aspect, soil texture, and arent material. Where prefire density was less han 200 bitterbrush per acre, a plotless method was used to determine resprouting potential. Four random groups of 25 plants were located. Individuals were identified as dead or alive. Resprouting was estimated from this sample regardless of how much area was required to locate the 25 plants. An estimate of seedling density was not made on these sample sites.

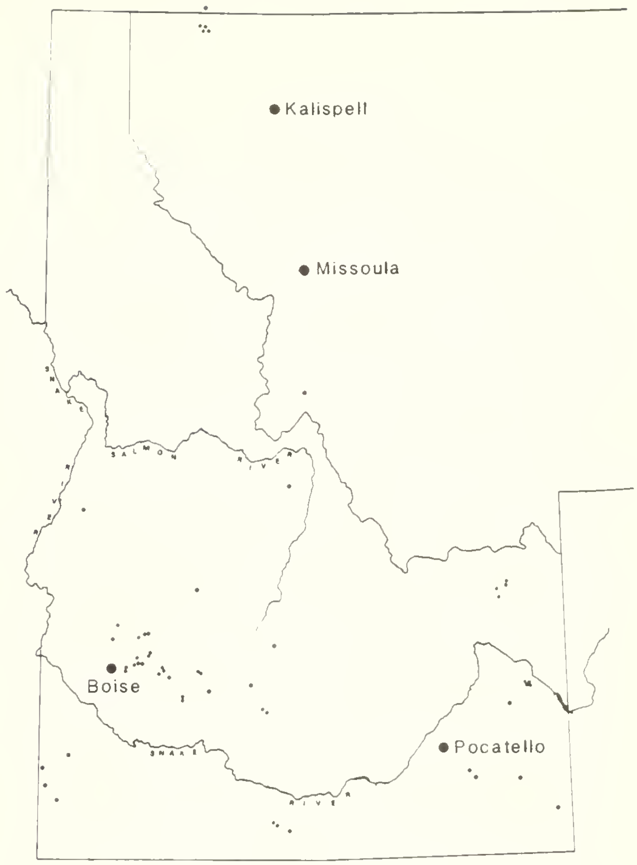

Figure 1.--Location of areas burned by prescribed burns or wildfires in the Northern Rocky Mountains which were sampled for bitterbrush resprouting frequency and establishment of seedlings.

The classification of habitat types follows Pfister and others (1977), Mueggler and Stewart (1980), Steele and others (1981), and Hironaka and others (1983), depending on the vegetation and area. A habitat type classification system for Utah juniper (*Juniperus osteosperma*) and western juniper (*J. occidentalis*) has not been developed for this region. These sample sites were classified only by the species of juniper present.

The other exception concerns a type of vegetation that has not been separately described. This vegetation has been included within the *Artemisia tridentata* ssp. *vaseyana-Symphoricarpos oreophilus/Festuca idahoensis* habitat type by Hironaka and others (1983) and will be referred to as "mountain shrub" in this paper. It is slightly more mesic than the typical *A. tridentata* ssp. *vaseyana-S. oreophilus/F. idahoensis* vegetation. It is characterized by the presence of one or more of the following shrubs: Saskatoon serviceberry (*Amelanchier alnifolia*), snowbrush ceanothus (*Ceanothus velutinus*), bitter cherry (*Prunus emarginata*), quaking aspen (*Populus tremuloides*), and squaw currant (*Ribes cereum*). Our experience indicated that this vegetation responds differently to fire than that included in the drier end of the habitat type as described by Hironaka and others (1983); it was, therefore, separated.

Bitterbrush does not occur as distinctly different growth forms over the entire region. Variation within the species is continuous between populations which are decumbent and multiple stemmed to those which are upright (columnar) and single stemmed. The latter may exceed 9.6 ft (3 m) in height. Growth form variation was separated into three classes. The decumbent form included those low-growing multiple-stemmed individuals (less than 3.28 ft (1 m) tall) which commonly reproduce by layering. Subcolumnar individuals included those which did not layer, were usually between 2.5 and 4.9 ft (75 to 150 cm) tall, and multiple stemmed. The columnar form included plants that were usually greater than 3.28 ft (1 m) tall, did not layer, and had few to a single main stem. Mature, unburned plants in the general vicinity were used to make this distinction. When more than one form occurred on a site, the dominant form was recorded.

The season and year of the fire were obtained from land management agency records. Fires were located that had occurred in various seasons and habitat types in order to balance the design of the study as much as possible.

One-way analysis of variance (ANOVA) and Duncan's Multiple Range Test were used to test the data for significant differences. More complex ANOVA could not be used due to the unbalanced nature of the data.

RESULTS AND DISCUSSION

Habitat type-form-season of fire combination was found impossible to completely balance. The three forms of bitterbrush do not occur within every habitat type sampled. In general, there is an elevation-moisture gradient associated with form. The decumbent form is found at the higher elevations and on more mesic sites. The columnar form occurs primarily at the lower elevations and on more xeric sites. The subcolumnar form was intermediate in regard to both variables. In some instances pure stands of two different forms may be found close to each other, depending upon the site. Thus, large differences in elevations were not always necessary to cause a change in form.

In addition, different habitat types were not likely to be burned in all seasons due to differences in fuel conditions. The decumbent form occurs in communities that are not frequently burned by wildfires. Prescribed fire, however, is more likely to be utilized in these communities at the present time. With the columnar form, the reverse is true. They are likely to be burned by wildfire and only rarely burned with prescribed fires. Prescribed fires were usually ignited in the spring and fall, and wildfires occurred primarily in the summer and fall.

The habitat types were grouped into five major categories of conifer, mountain shrub, mountain b sagebrush, basin big sagebrush, and juniper (table 1). Bitterbrush responded similarly to fi in habitat types or communities within each group

Resprouting

The decumbent form of bitterbrush resprouted more frequently than the other two forms (table 2), whereas the subcolumnar form resprouted on the average two times as frequently as the columnar form. The difference, however, was not significant. Columnar and subcolumnar forms resprout fr a mass of dormant buds at ground level or from a callus of meristematic tissue above the ground level as described by Blaisdell and Mueggler (1956). The decumbent forms resprout from the central bud mass and from bud masses that form at the points where the branches layer. It was observed that when fire killed the above-ground connecting branches, the separate resprouting bud masses may no longer be interconnected. These individual bud masses may be over 3.28 ft (1 m) from the parent bud mass.

Resprouting frequencies of bitterbrush on sites burned in the spring- and fall-burned sites averaged 55 and 42 percent, respectively, but wer not significantly different (table 3). Resprouti was less frequent on the summer-burned sites and averaged 21 percent. Summer fire may be more destructive to bitterbrush because burns occur during a period of lowest carbohydrate reserves (Menke and Trlica 1981), and summer is also when the most severe fires occur.

The highest resprouting potential of the five habitat groups was found to be in the mountain shrub and the conifer groups, with 60 and 49 percent of the plants surviving, respectively (table 4). The bitterbrush populations in these groups are composed primarily of decumbent plants The mountain big sagebrush group is also dominate by the decumbent form, but resprouting was signif cantly lower than in the first two habitat groups The habitat types in this group are slightly more xeric than those in the mountain shrub or conifer groups. Basin big sagebrush and juniper habitat groups had the lowest resprouting potential. The groups were dominated by columnar and subcolumnar forms of bitterbrush.

Seedling Establishment

Seedling establishment rates appeared to be most affected by moisture gradient (tables 2, 3, and 4 Postfire seedling densities were greater on the more mesic habitat types such as the conifer grou Seedling density was greatest on areas burned in

Table 1.--List of habitat types and other communities included within the analysis groups used in this study

Community or habitat type group	Habitat types and communities included within group	Reference
Conifer	*Pseudotsuga menziesii/ Symphoricarpos albus* ht	Pfister and others 1977
	Pseudotsuga menziesii/ Symphoricarpos oreophilus ht	Pfister and others 1977 Steele and others 1981
	Pinus ponderosa/Purshia tridentata ht	Pfister and others 1977 Steele and others 1981
Mountain shrub	*Artemisia tridentata* ssp. *vaseyana-Symphoricarpos oreophilus/Festuca idahoensis* (mesic phase) ht	Adapted from Hironaka and others 1983
Mountain big sagebrush	*Artemisia tridentata* ssp. *vaseyana-Symphoricarpos oreophilus/Festuca idahoensis* (dry phase) ht	Hironaka and others 1983
	Artemsia tridentata ssp. *vaseyana/Festuca idahoensis* ht	Hironaka and others 1983 Mueggler and Stewart 1980
Basin big sagebrush	*Artemisia tridentata* ssp. *vaseyana f. "xericensis"*[1] *Agropyron spicatum* ht	Hironaka and others 1983
	Artemisia tridentata ssp. *tridentata/Agropyron spicatum*	Hironaka and others 1983 Mueggler and Stewart 1980
Juniper	Includes all communities in which *Purshia tridentata* occurs with *Juniperus osteosperma* or *J. occidentalis*. At this date these habitat types have not been described for the region sampled.	

[1] Currently this taxon of *Artemisia* has not been officially established by taxonomists, but has been referred to by Winward and Tisdale (1977).

lte winter or spring and least on areas burned in te summer (table 3). The rate of seedling etablishment closely corresponds to resprouting ptential. In general, the greater the ability to rsprout, the greater the likelihood of seedling etablishment. A notable exception is the conifer goup. Although its average resprouting potential ws slightly less than that of the mountain shrub, erage seedling density was two times greater for te conifer group (table 4).

The lowest seedling density was found in the juniper group (table 4). We do not know why the rate is so low. Both the juniper and basin big sagebrush groups are usually dominated by the columnar form. Cheatgrass (*Bromus tectorum*), which competes with bitterbrush seedlings for soil moisture, was usually less prevalent within the juniper vegetation than in basin big sagebrush. Slow regeneration of bitterbrush on juniper sites probably involves more than plant competition. Precipitation in the

Table 2.--Percentage bitterbrush resprouting and seedling density 3 to 10 years after fire as affected by bitterbrush growth form in the Northern Rocky Mountains.

Growth form	Resprouting Mean[1]	n[2]	Seedling density Mean[1]	n[2]
	Percent		No./acre (No./ha)	
Decumbent	57a	28	189 (467)a	26
Subcolumnar	18b	12	87 (209)a	11
Columnar	7b	16	29 (71)a	9

[1] Values within a column followed by the same letter are not significantly different ($P \le 0.05$) as determined by Duncan's Multiple Range Test.

[2] n is the sample size and varies within a growth form between resprouting and seedling density because density could not be sampled on all sites.

Table 3.--Percentage bitterbrush resprouting and seedling density 3 to 10 years after fire as affected by season of the fire

Fire season	Resprouting Mean[1]	n[2]	Seedling density Mean[1]	n[2]
	Percent		No./acre (No./ha)	
Late winter-spring	55a	10	266 (658)a	9
Fall	42a	19	136 (335)ab	16
Summer	21b	27	73 (181)b	21

[1] Values within a column followed by the same letter are not significantly different ($P \le 0.05$) as determined by Duncan's Multiple Range Test.

[2] n is the sample size and varies within a season between resprouting and seedling density because density could not be sampled on all sites.

juniper types at least equals that of the basin big sagebrush group, so this probably is not a factor. Precipitation is low, however, in both types. The prefire density of bitterbrush was also approximately equal. It has been observed that seed production by bitterbrush on sites occupied by juniper is reduced as the juniper begins to dominate the site. This reduction would deplete seed reserves in the soil. This phenomenon has not been observed on sites occupied by sagebrush (Monsen 1984). Ferguson (1972) found soil moisture and surface temperature to be important in seedling establishment. In general, the juniper sites were more productive, cooler in summer, and not subject to as variable temperatures during the winter as the basin big sagebrush sites. It may be that large rodent populations remove seeds and girdle seedlings. The relationship of prefire and postfire rodent populations between the two groups is not known. Other research has shown that rodents have a significant impact on bitterbrush establishment from seed (Hubbard and McKeever 1961). On one burned site in this study, 25 seedlings were permanently marked with stakes. Close inspection of the burned area during the third year revealed that no seedlings had survived even through they were numerous the first 2 years after the fire. Browsing by rodents or rabbits was determined to have been the cause. This indicates the impact that rodents may have on bitterbrush regeneration.

Soil stability may be a factor in seedling establishment. Grazing by livestock after fire on unstable granitic soils near Horseshoe Bend, Idaho, had displaced substantial amounts of soil on the 56 percent slopes. The density of seedlings on this site was 145 per acre (360 per ha), which was the greatest of the sites dominated by the columnar form. The majority of seedlings were single plants, which indicated that they were not from rodent seed caches. This suggests that seed burial was a factor in seedling establishment.

Fall is believed to be the best time for prescribed burning if seedling establishment is a major consideration (Monsen and Christensen 1975). Fall burns occur after the current year's seed has fallen from the plants and the seed availability is maximized. This study, however, found two times as

Table 4.--Percent bitterbrush resprouting and seedl density 3 to 10 years after fire as affec by major habitat type groups or communiti in the Northern Rocky Mountains

Community or habitat type group	Resprouting Mean[1]	n[2]	Seedling density Mean[1]	n[2]
	Percent		No./acre (No./ha)	
Mountain shrub	60a	12	107 (264)ab	11
Conifer	49a	15	260 (643)a	14
Mountain big sagebrush	28b	11	94 (231)ab	10
Basin big sagebrush	11bc	10	54 (133)b	6
Juniper	6c	8	6 (16)b	5

[1] Values within a column followed by the same letter are not significantly different ($P \le 0.05$) as determined by Duncan's Multiple Range Test.

[2] n is the sample size and varies within a season between resprouting and seedling density because seedling density could not be sampled on all sites.

ny seedlings on spring burns than fall burns,
though the difference was not significant (table
. It seems that fire severity and environmental
nditions after the burn may be more important in
edling establishment than the number of seeds
esent.

anges in Density Following Fire

en considering the short-term effects of fire on
tterbrush populations, overall changes in density
y be more important than either mortality or seed-
ng establishment. Changes in density are presented
habitat group in table 5. The smallest decrease
average density occurred in the conifer habitat
oup. Although the mountain shrub group had the
eatest average number of resprouts (table 4), the
gher seedling establishment in the conifer group
re than compensated for this difference. The
nifer group with density increases on 4 of 14
tes was also the only group in which density
creased after fire. One site had 57 percent more
tterbrush plants after a fire than before it was
rned.

e greatest decrease in bitterbrush density follow-
g fire occurred in the juniper group, which has
w resprouting combined with low seedling establish-
nt. The average decrease in this group was
percent. This poor response makes the management
bitterbrush difficult in the juniper communities
cause bitterbrush is poorly adapted to fire. It
probably fire dependent, however, in many of the
mmunities in the Northern Rocky Mountains. It
s been our observation that without fire or some
her disturbance that removes the juniper, bitter-
ush will eventually be replaced by the developing
iper stand. Similar results have been reported
Young and Evans (1981) for California.

ble 5.--Change in density of bitterbrush following fire by habitat type group or community averaged across season and growth form in the Northern Rocky Mountains

Cmmunity hbitat type group	Change in density[1]	Standard deviation	Range Minimum	 Maximum
	percent			
Cnifer	-11	±36.9	- 62	+57
Muntain shrub	-30	±28.2	- 87	0
Muntain big sagebrush	-55	±30.6	-100	0
Bsin big sagebrush	-68	±10.4	- 79	-54
Jniper	-91	±11.2	-100	-73

[1] Density change includes resprouting and
sedling establishment 3 to 10 years after fire
ccurred minus mortality.

MANAGEMENT IMPLICATIONS

It is a common belief among land managers that prescribed burning has no role in the management of bitterbrush. This conclusion is based on the premise that bitterbrush is fire sensitive and needs protection. This study and others have shown that although variation in response to fire occurs due to growth form, habitat type, season of the fire, and other factors, some bitterbrush mortality should be expected in almost all situations. Seedling establishment also varies, but seldom compensates for the mortality in those areas where bitterbrush is not well adapted to fire in the short term (less than 10 years). Many prescribed fires in communities where bitterbrush is a component of the vegetation are currently conducted for objectives other than bitterbrush management. These objectives include sagebrush (*Artemisia* spp.) control, increased herbaceous production, or slash disposal. In these instances, prescribed burns may be conducted in a manner that minimizes the loss of bitterbrush or may be canceled because the bitterbrush losses are judged to be unacceptable. This and other research enable the manager to predict the short-term effects of fire on bitterbrush. The question then remains as to what, if any, is the role of prescribed burning in bitterbrush management.

In the Northern Rocky Mountain area, bitterbrush occurs as a component of many forested and nonforested habitat types. It may be present at the seral or climax stage or throughout the entire successional sequence. Even in those communities where it is a part of the climax vegetation, it may act as a pioneer species. Given a seed source, it is often one of the first species to reoccupy a disturbed site such as a roadcut (Nord 1965). Bitterbrush has also been shown to increase after other disturbances such as logging (Stuth and Winward 1976; Edgerton 1983) and fire (Sherman and Chilcote 1972; Driver and others 1980; Martin 1983). Consequently, it is important to realize the successional status of bitterbrush within the particular community and that these communities are dynamic, not static, even at the climax stage.

Our study and others have shown wide differences in the response of bitterbrush to fire; these differences depend upon several variables. These findings demonstrate that it may be ecologically sound to use fire in bitterbrush management. The level of fire use, however, varies with the situation.

The role of prescribed burning in the management of bitterbrush within the mesic forested communities, such as Douglas-fir (*Pseudotsuga menziesii*), is that of maintaining a subclimax community type. Peek and others (1978) found that bitterbrush was declining in a seral ponderosa pine (*Pinus ponderosa*) stand that had been protected from grazing and fire. The site was a Douglas-fir/snowberry (*Symphoricarpos albus*) habitat type. They stated that if the vegetation proceeded to the climax composition, bitterbrush would disappear from the community. This decline is now occurring within many bitterbrush stands in the Northern Rocky Mountain region.

Our data support the use of prescribed fire to regenerate bitterbrush in seral ponderosa pine stands. There are opportunities to either underburn or selectively log and burn in conifer types for bitterbrush improvement. Application of spring or fall prescribed fire would allow a rather high rate of resprouting of bitterbrush which are primarily decumbent. Establishment of many bitterbrush seedlings can be expected. This conclusion is similar to that drawn by Driver (1983) for ponderosa pine.

Bitterbrush is a climax component of the ponderosa pine/bitterbrush habitat type. Even in these communities, productivity and density will decline without periodic disturbance. Initially, bitterbrush increased on these areas as a result of fire protection (Leopold 1950; Weaver 1957; Johnson and Smathers 1974). With continued protection, however, many populations have become decadent. Sherman and Chilcote (1972) found that bitterbrush declined in density from 25 to 100 years following a fire. It has also been shown that productivity of individual plants greater than 70 years old declines (McConnell and Smith 1977). Fire suppression may reduce reproduction by reducing the available microsites for rodents to cache seeds since they prefer microsites with thin layers of litter (Sherman and Chilcote 1972). The establishment of bitterbrush seedlings on undisturbed sites is probably also regulated by competition. Any factor reducing competition enhances seedling survival. Litter accumulation also changes soil characteristics (Zinke 1962) which may influence seedling establishment.

The response of bitterbrush within the western juniper and pinyon-juniper communities is much different than the response in the more mesic forest types. In these communities, bitterbrush usually develops the columnar growth form, which is least adapted to fire. Our data indicated the lowest resprouting potential and number of established seedlings of bitterbrush in the juniper communities of those habitat types studied. It may seem logical then to restrict the use of fire in these communities in order to maintain the stands of bitterbrush; however, unless fire is permitted periodically into these areas the juniper will increase in density and invade adjacent sagebrush/grassland vegetation (Burkhardt and Tisdale 1976). Increasing dominance of juniper in a community decreases the understory shrub and herbaceous species. Consequently, with continued protection from fire the bitterbrush in these communities will be replaced by other species. Young and Evans (1981) found vigorous bitterbrush only in open stands of juniper. They suggested that these were probably areas that had previously burned and were being reinvaded by juniper. In dense juniper stands, the bitterbrush was dead or had very low vigor. It appears that even though bitterbrush is not well adapted to fire in these communities, it depends upon fire to maintain a lower successional stage than climax juniper.

Periodic fire will be necessary to maintain bitterbrush in juniper communities. The fire-free interval will need to be sufficiently long to allow the bitterbrush to redevelop. If the interval is too long, the reinvading juniper will eliminate th bitterbrush seed source. The development of a new bitterbrush stand will require more time because the seeds will have to be transported onto the bur from other areas. Dense juniper stands do not readily burn due to the lack of fine fuels; howeve when they do burn the fires are usually severe. High-severity fires will also reduce the number of surviving plants. This situation is becoming common in many juniper communities at this time.

The role of prescribed fire in the management of bitterbrush in nonforested habitat types is less clear than that in the forested communities. Sinc these types are not occupied by trees, the decline in bitterbrush density and vigor is not as readily apparent even after long periods of fire absence. There is some evidence, however, that fire or othe disturbance may be necessary to establish new bitterbrush plants in these communities. McConnel and Smith (1977) found that the productivity of bitterbrush was correlated to age regardless of browsing intensity. Annual production increased t a maximum at 60 to 70 years of age and then declined. In Idaho, it was found that deer browsing was not a significant factor in vegetatio change over a 23-year period. Bitterbrush annual production and density decreased while canopy coverage increased (Ferguson and Medin 1983).

Bitterbrush associated with mountain big sagebrush is usually well adapted to fire. The bitterbrush present usually are of the decumbent form or, rarely, subcolumnar. Resprouting frequency averag 45 percent in the nonforested communities where mountain big sagebrush was present. Prescribed fire is frequently used in these communities for sagebrush control. Coverage of mountain big sagebrush is among the greatest found in *Artemisia* types and may exceed 40 percent. Fire is an effective means to stimulate production of these communities. Initially, the herbaceous component is enhanced. Nearly all shrubs, including bitterbrush and mountain big sagebrush, establish more rapidly from resprouts or seed than many other sagebrush communities. Consequently, the productivity of the shrub component is also enhanced in the long term by periodic fire in many situations. Spring fires give the best results in this vegetation, but spring prescribed burning may be limited in some areas due to the climate. Most shrubs, including bitterbrush, also respond well to low-severity fall prescribed fires, however.

Bitterbrush in the basin big sagebrush and "specie X" (*Artemisia vaseyana* f. "*xericensis*") (Winward and Tisdale 1977) communities are more seriously damaged by fire than those associated with mountai big sagebrush. They are usually columnar or subcolumnar forms which resprout poorly and do not readily establish from seed. Many of these commun ties are also heavily invaded by cheatgrass. This has altered the plant competition relationships, particularly at the bitterbrush seedling stage.

Cheatgrass, an exotic, has also altered the fire relationships in these areas by changing fuel distribution and amount. Since the invasion of eatgrass, fires in these communities are likely re continuous than previously. The fire-free terval of fires in cheatgrass dominated areas is orter. Cheatgrass responds favorably to fire, d fuels can return to sufficient levels to carry other fire within 1 to 2 years.

e role of fire in these communities before ttlement is not known. It has been suggested at because the recovery of bitterbrush may take years, the fire frequency would have been about years for bitterbrush to exist (Wright and iley 1982). It has also been suggested that the re interval was short and that many of the shrubs re not present in the densities we observe today ruell in preparation). This may have been the se with bitterbrush in the "species X" communi- es, which are often productive sites on moderate steep slopes. They burn frequently today as a sult of lightning and human-caused fires. Even ough cheatgrass has increased the fire potential, is probable that frequent Indian- and lightning- used fires held bitterbrush to low levels in this mmunity in presettlement times.

e current fire frequency combined with the poor aptation of bitterbrush to fire in "species X" mmunities makes continued maintenance of bitter- ush difficult without artificial planting as ggested by Ferguson and Medin (1983). Another ssibility is the development of a more fire- apted cultivar of bitterbrush or the introduction a resprouting browse species into these areas.

conclude that although bitterbrush density ually decreases initially following fire, the ntinued productivity and dominance in a mmunity of bitterbrush is disturbance-dependent. many instances, continued protection from fire ll result in low rates of reproduction and clining productivity. Proper application of escribed fire may be used to maintain vigorous tterbrush stands on a long-term basis. As nagers we must not be so concerned with ort-term effects that we lose sight of the ture needs of the species and those animals that e dependent upon it.

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INFLUENCE OF FIRE ON CURLLEAF MOUNTAIN-MAHOGANY IN THE INTERMOUNTAIN WEST

G. Gruell, S. Bunting, and L. Neuenschwander

ABSTRACT: Comprehensive sampling of curlleaf mountain-mahogany (*Cercocarpus ledifolius*) on 41 sites in five States allowed an assessment of postfire population dynamics, differences in regeneration patterns, and critical events in stand regeneration. Historical accounts of fire, fire history studies, and early photographs provided historical perspective and contributed to interpretations.

The combined quantitative and historical evidence strongly suggests that before European settlement, fire significantly influenced mahogany in the Northern Rockies by restricting its development. A reduction of fire periodicity and size following Euroamerican settlement apparently allowed mahogany seedlings to regenerate far in excess of former levels. The absence of fire for long periods has resulted in great variation in structure of mahogany stands. Many stands are in a declining condition because the absence of fire has allowed them to reach advanced stages of succession. In some areas, closure of mahogany crowns, excessive litter accumulation, and competition from other vegetation are inhibiting regeneration. In other areas, young vigorous mahogany predominate. These wide differences in stand conditions suggest different management strategies. Many mahogany communities would respond positively to fire, whereas others would not. Management implications are given.

INTRODUCTION

Curlleaf mountain-mahogany, hereafter referred to as mahogany, is an important forage and cover plant on many game ranges in the Northern Rocky Mountains. Various questions about proper management of mahogany ecosystems have surfaced in recent years because of incomplete knowledge of regeneration potential. A primary question involves the role of fire. Mahogany grows in regions where fire has been a common ecological disturbance; however, there has been little research on the effects of fire on long-term mahogany production. To determine whether prescribed fire has a place in future management strategies, it is important to understand the past role of fire in representative mahogany types.

To understand the role of fire in managing mahogany, we conducted comprehensive sampling of mahogany stands on a wide range of sites in Idaho, Montana, and adjacent portions of Nevada, Utah, and Wyoming that were representative of stands in the Intermountain West. In this region mahogany is present in over 20 forested or nonforested habitat types (Henderson and others unpubl.; Hironaka and others 1983; Mueggler and Stewart 1980; Pfister and others 1977; Steele and others 1981). In the forested communities, mahogany may be potential climax or seral, but in the nonforested communities where it occurs, mahogany is potential climax. We assessed the postfire population dynamics, differences in regeneration patterns, and critical events in mahogany regeneration.

Quantitative data gathered at 41 locations (fig. 1) were complemented by fire history studies, fire occurrence records, historical literature, and comparison of historical photographs with recent photographs taken in mahogany types. Study findings allowed us to make implications for fire management, including use of prescribed fire in mahogany types.

PAST RESEARCH

Mahogany is widely distributed throughout semiarid regions of the Intermountain West from eastern California to southwestern Montana and north-entral Wyoming (Little 1976). Growth forms vary rom low shrubs to plants that may reach 30 ft 9 m) in height on productive sites. Older plants ay exceed 300 years in age.

hogany is a highly palatable forage for mule deer (*Odocoileus hemionus*) (Smith 1952), and it is a preferred browse (Kufeld and others 1973). Stands in many regions have grown above the reach of big game and are no longer a source of forage. These stands are, however, a valuable seed source and important hiding cover (Dealy 1971). Heavy winter utilization has been widely reported (Deitz

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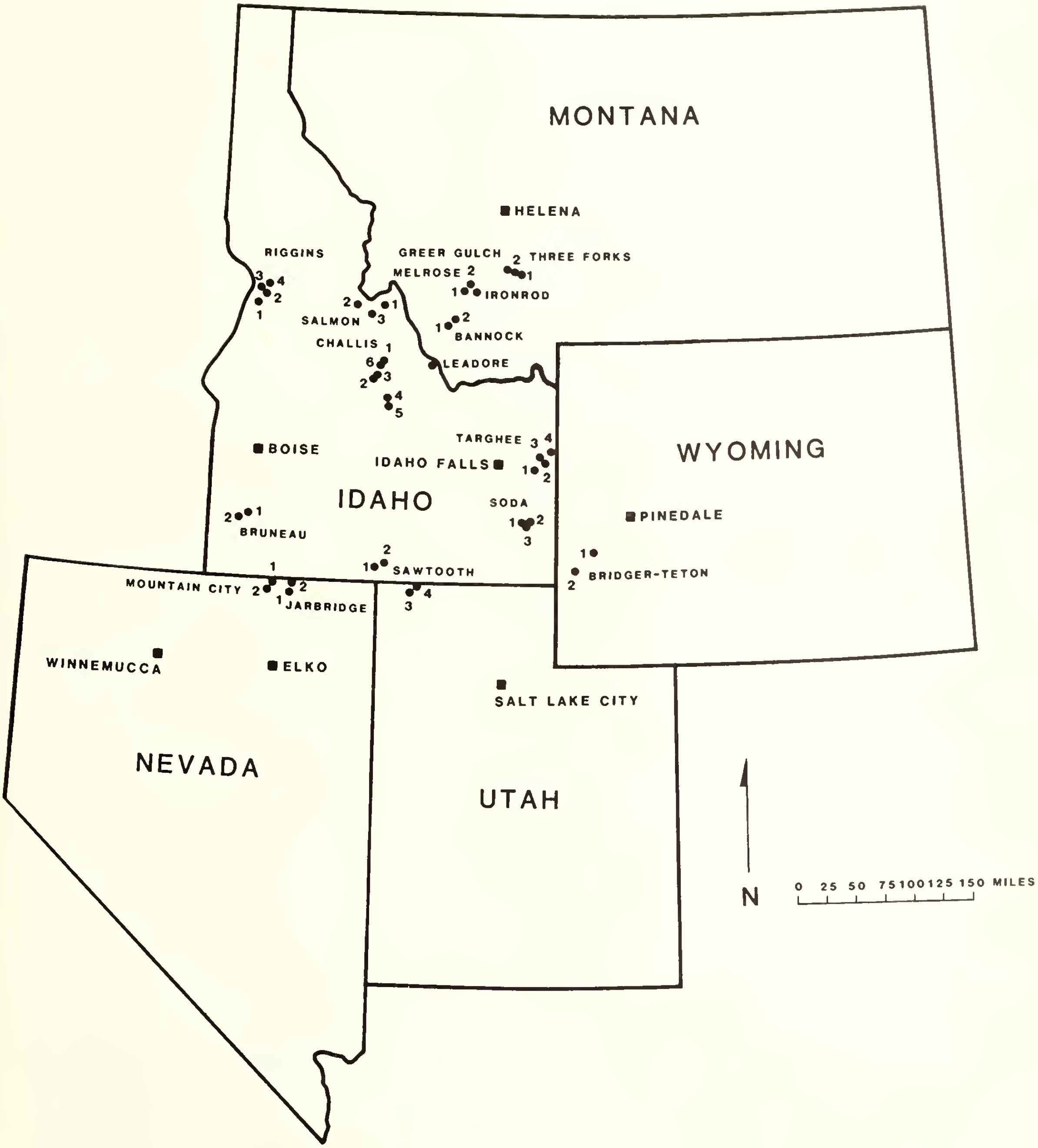


Figure 1.--Location of the 41 mahogany sampling sites. See table 1 for description of site characteristics.

and Nagy 1976; Claar 1973; Richens 1967). In southwestern Montana heavy utilization by ungulates was believed to have been responsible for a deterioration of mahogany stands (South 1957). In contrast, Claar (1973) concluded that decades of heavy browsing by big game in central Idaho had not caused mahogany to deteriorate. Plant losses were compensated by establishment of seedlings. Mackie (1973) concluded that high-level ungulate use over a 5- to 23-year period on two Montana winter ranges had not been responsible for decreased plant populations, browse production, or both.

Researchers working on the ecology of mahogany have postulated fire effects. Dealy (1975) in eastern Oregon and Scheldt (1969) in Idaho reported that the existence of mahogany was related to the fire protection afforded by rocky sites. They also concluded that most mahogany stands on deep soils were less than 100 years old and that tree age seemed to correlate closely to the advent of fire control and use of forage by livestock that otherwise would have fueled fires.

Montana studies that included age determination of mahogany implicitly showed the relationship of age to absence of fire. Duncan (1975) found an average age of 22 years (range 5 to 85 years) for 210 randomly chosen plants in 21 southwestern Montana stands. Lonner (1972) reports the average age of 62 mahogany plants collected on Montana big game winter ranges was 37 years (range 2 to 130 years).

The beneficial influence of fire has also been reported. Claar (1973) concluded that fire seemed to be essential to set succession back and maintain seral mahogany on drier sites associated with adjacent Douglas-fir/ninebark habitat types.

Mahogany, a weak sprouter (Wright and others 1979), is highly susceptible to fire, which results in heavy mortality. It sprouts from undamaged auxiliary buds on the stems or from adventitious buds beneath the bark. Unlike many shrubs, it has a thick bark that allows it to survive light fires when mature and does not sprout from a basal caudex or rhizomes. Sprouting may occur after light burning, but reproduction almost entirely depends on seedling establishment.

Mahogany has successfully regenerated from seed after stands were cut. Dealy (1975) reported that young stands in two Oregon localities developed following intensive cutting for firewood during the late 1800's and early 1900's. Experimental cutting and bulldozing of mahogany on the Targhee and Cache National Forests during the 1960's resulted in germination of many seedlings (Phillips 1970). Seedling germination was heavy on mineral soil that was bared of litter and plant competition. High seedling mortality may occur, however, apparently the result of summer drought.

Marked reductions in mahogany forage availability have led to attempts to increase productivity by top pruning (Austin and Urness 1980; Ormiston 1978; Phillips 1970; Thompson 1970). These experiments indicated that production can be temporarily increased in the browsing zone by pruning plants above a point where there are numerous live twigs. Where large treelike mahogany predominates, however, the scarcity of twigs within the browsing zone precludes pruning as a practical treatment measure. No sprouting from adventitious buds below the cut was reported. Attempts to improve forage availability by pushing over younger mahoganies with a bulldozer have succeeded (Phillips 1970); however, older mahogany usually die when pushed over (Dealy 1971).

HISTORICAL PERSPECTIVE

Examination of historical accounts showed that wildfire was a major perturbation in semiarid regions of the Interior West from at least 1776 to 1900 (Gruell in press). Many of these fires were set by Indians (Gruell in press). Some of these accounts described the beneficial effects of fire in stimulating grasses and suppressing woody plants.

Study of the scars on trees indicates that before Euroamerican settlement fire intervals averaged from 5 to 20 years in ponderosa pine/Douglas-fir (*Pinus ponderosa/Pseudotsuga menziesii*) forests in the Bitterroot Valley of western Montana (Arno and Peterson 1983). Scar data from higher and cooler Douglas-fir/sagebrush (*Artemisia tridentata* subsp. *vaseyana*) ecotones in Yellowstone Park and southwestern Montana indicated that fire intervals were 20 to 40 years (Houston 1973; Arno and Gruell 1983). Fire scar evidence in Ephraim Canyon, Utah, indicated an average fire interval of from 7 to 10 years in aspen (*Populus tremuloides*) during the period 1770 to 1875 (Baker 1925). Working in southwestern Idaho, Burkhardt and Tisdale (1976) reported that presettlement fire intervals were about 11 years in sagebrush-grass/western juniper (*Juniperus occidentalis*) ecotones.

An examination of early photographs provided insights about the historical appearance of mahogany stands (Gruell 1983). Figures 2 and 3 are some of the earliest scenes found within the study area. These 1868 and circa 1871 scenes show mahogany confined to protected rocky sites or thin soils where fire was infrequent. Recent field inspection revealed evidence of pre-1868 fire within the scene at figure 2. On other sites (fig. 3) some mahogany plants had apparently resisted light surface fires but were killed by a more severe fire before 1871. Figure 4 shows an example of mahogany regeneration following cutting.

METHODS

Mahogany density varied greatly among communities. To provide consistent sampling among study sites, stands had to meet the following criteria to be selected:

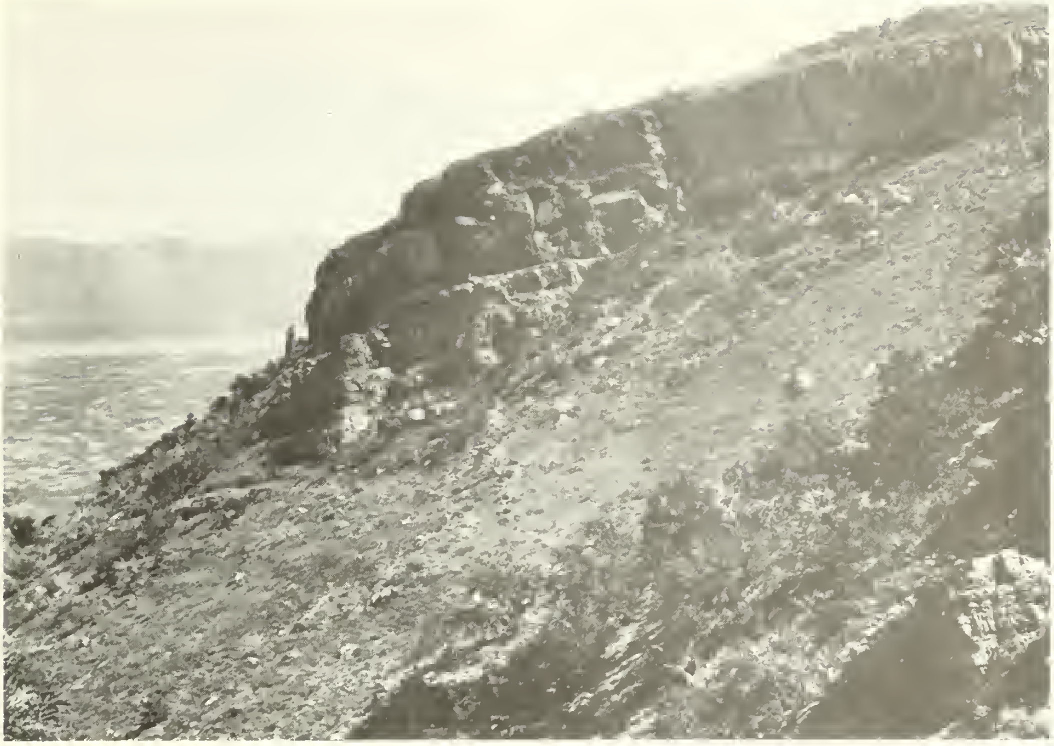


Figure 2a.--Looking east-southeast down canyon toward Ruby Marsh from a point about 1.5 miles above Flyn and Hager Spring (elevation 7,500 ft)(1868). Note the scattered distribution of living and dead fire-killed mountain-mahogany in lower left quarter of photo.

Photograph by Timothy O'Sullivan. Courtesy of U.S. Geological Survey, Denver, Colo.

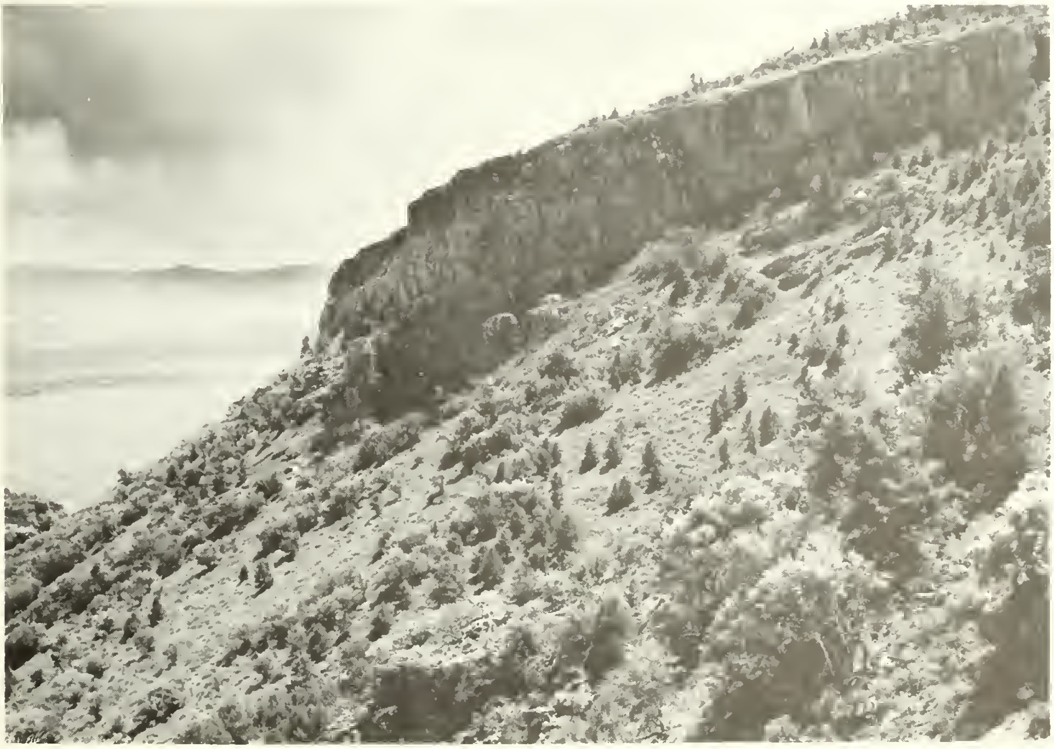


Figure 2b.--Photo taken July 31, 1982. The absence of fire since the 1840's or earlier has allowed mountain-mahogany and other woody vegetation to increase. Charred material in mahoganies verified loss of mahogany to fire before 1868.

Photograph by G. E. Gruell.

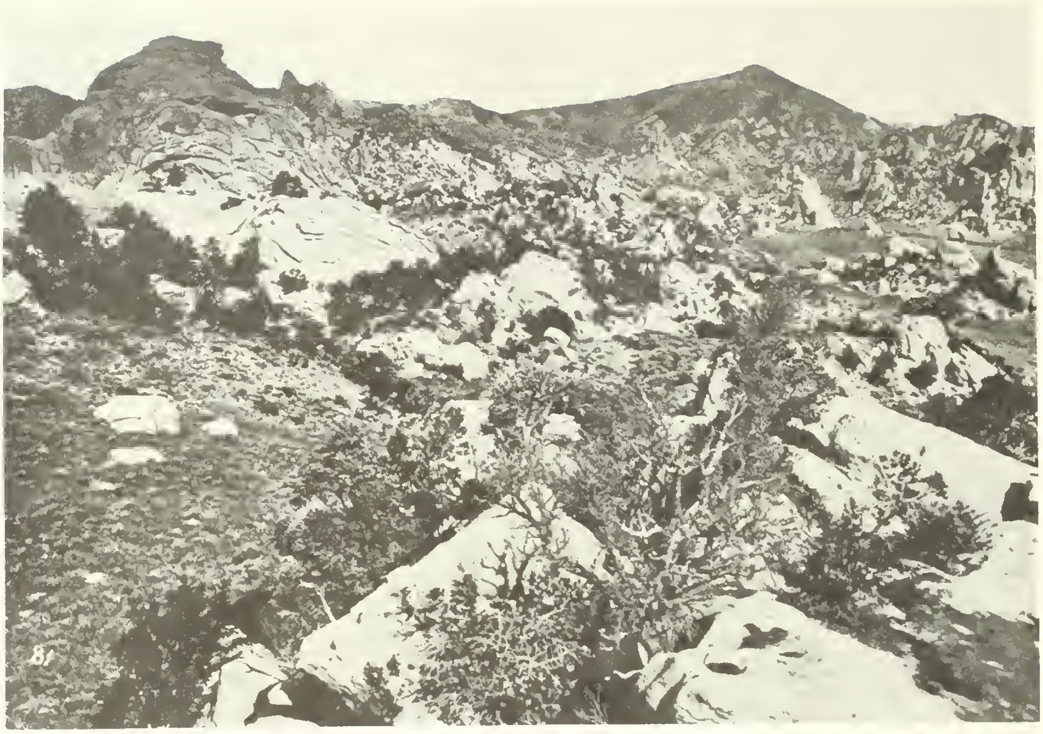


Figure 3a.--Looking north from a point adjacent to county road in southeast quarter of City of Rocks, Idah (elevation 6,400 ft). Woody plants include singleleaf pinyon pine (*Pinus monophylla*), Utah juniper (*Juniperus osteosperma*), and mountain-mahogany. Note the dead branches in foreground and absence of large woody plants in the smaller openings between rocks.

Photograph by Timothy O'Sullivan. Courtesy of U.S. Geological Survey, Denver, Colo.

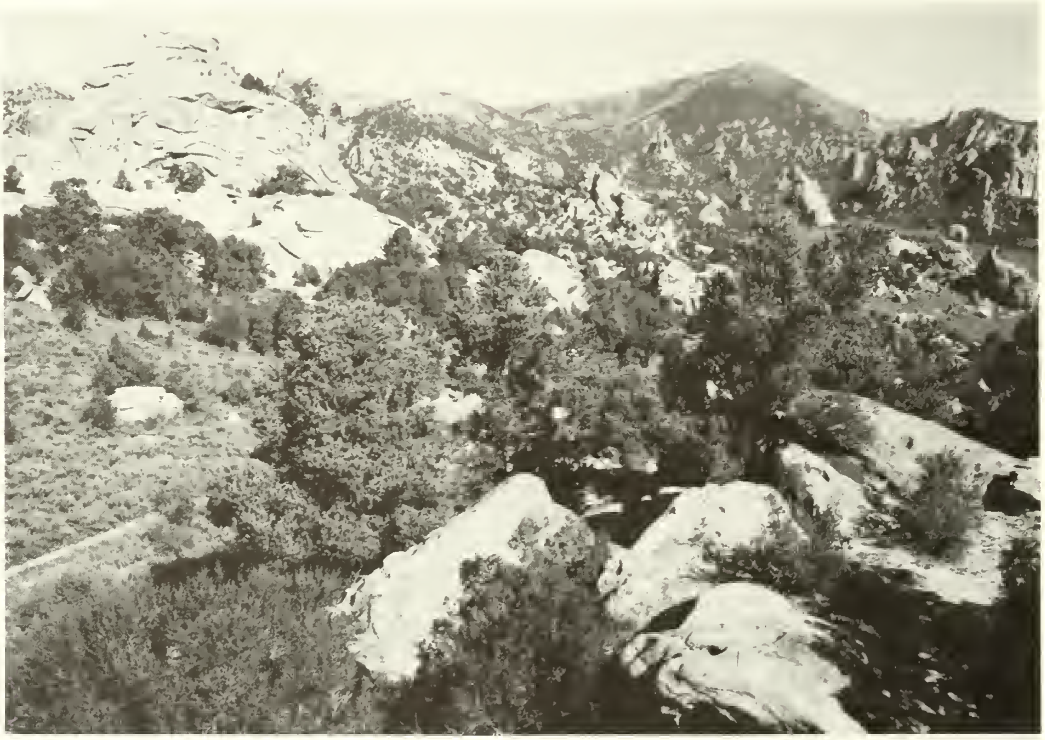
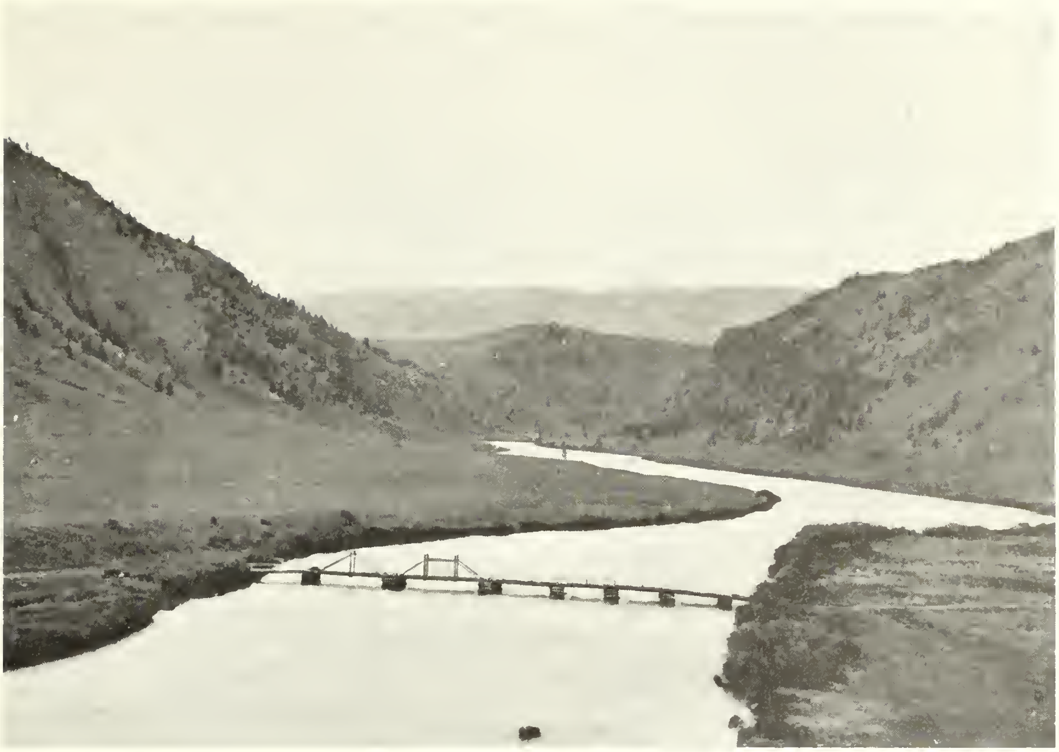


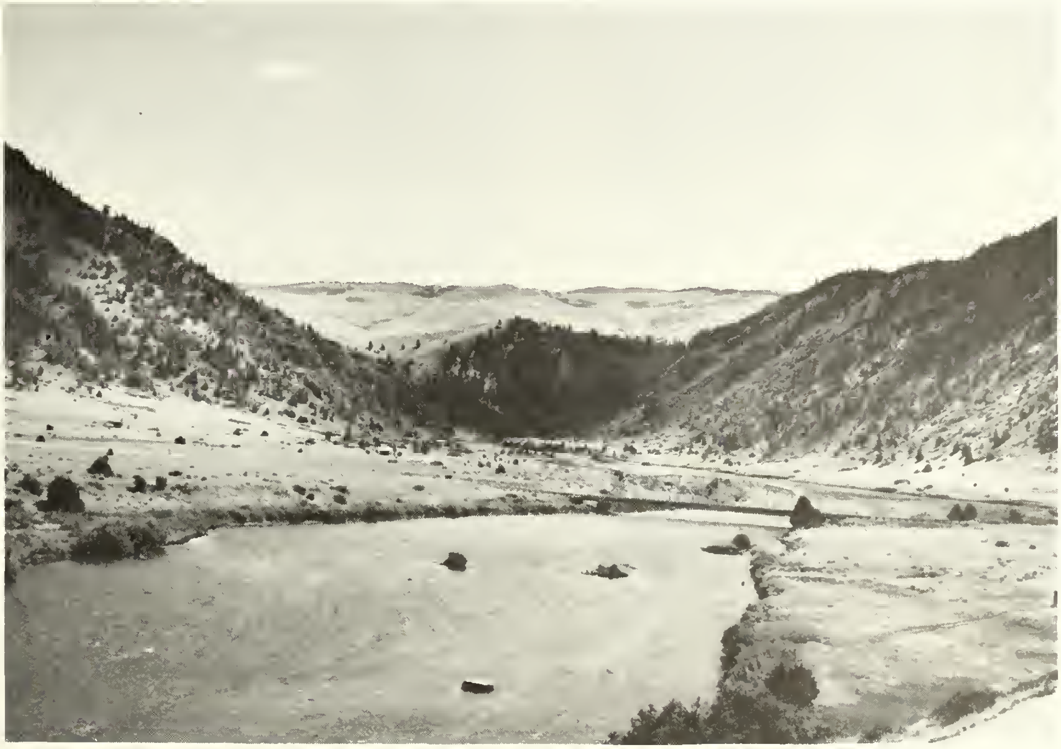
Figure 3b.--Photo taken August 20, 1983. Absence of fire over 100 years has allowed woody plants to proliferate. Sagebrush has increased in opening at left and on flats at right. Mountain-mahogany mixed with pinyon pine and juniper have invaded the deeper soils in openings. Sometime after 1872, a fire swep the upper slopes on distant mountain on right.

Photograph by G. E. Gruell.



igure 4a.--Photo taken in 1871. Camera faces south-southeast from position on west bank of Madison River ear present day Highway 84 crossing at Beartrap Recreation area (elevation 8,500 ft). Distant slopes upport Douglas-fir (*Pseudotsuga menziesii*), limber pine (*Pinus flexilis*), Rocky Mountain juniper *Juniperus scopulorum*), and mountain-mahogany.

hotograph by W. H. Jackson. Courtesy of U.S. Geological Survey, Denver, Colo.



igure 4b.--Photo taken August 31, 1982. Douglas-fir was cut after original photo was taken. Fire-scarred tumps indicate fires had occurred every few decades before settlement. Removal of conifers and absence of ire allowed great increase in mahogany. Note distant slopes above bridge.

hotograph by G. E. Gruell.

1. Minimum density of 10 mature mahogany per acre (25 per hectare) (in the case of recently burned stands the preburn density had to exceed 10 plants per acre).
2. A minimum stand diameter of 164 ft (50 m).
3. Reasonable accessibility.

Stands meeting these criteria were identified during a prestudy reconnaissance. A random sample of these stands was then selected using a random number table.

Fire-scarred cross sections were collected from all stands in which scarred mahogany occurred. These data aided in interpreting the role of fire in sampled communities. Stands burned on a known date or with a known history of other types of disturbance such as logging were chosen for sampling.

In each stand, the center points for four azimuths were randomly determined. Along each azimuth, a 13- by 66-ft (4- by 20-m) belt transect was used to measure the density of mahogany. The stem diameter near ground level was recorded. Where stands were dense, the belt transect was reduced to a width of 3.28 ft (1 m).

The age-diameter relationship for each stand was determined by randomly selecting 8 to 15 mahogany plants representing the size classes present. Height, maximum crown spread, and basal diameter of the plant were recorded, and a cross-section at the base was then collected. In the laboratory, cross-sections were sanded and annual growth rings counted with the use of a 10- to 50-power dissecting microscope. Ring counts were not considered precise because of the likelihood of false or missing rings. Data from 307 cross-sections were used in regression analysis to develop a model to estimate the age of mahogany.

Litter depth and seedling density were measured within a 3.28- by 66-ft (1- by 20-m) belt transect along each of the azimuths.

Cover of trees, mahogany, shrubs, perennial grasses, perennial forbs, annuals, and bare ground were estimated on circular plots with a radius of 3.28 ft (1 m). Five plots were located along each of the random azimuths at 16 ft (5 m) intervals. Mahogany canopy cover was also estimated by line intercept along the transect lines.

Additional site data collected on each stand included elevation, aspect, slope, vegetational competition, habitat type, surface soil texture, parent material, and time since last fire if known.

RESULTS

Age Determination

Results of the regression analysis indicated that basal diameter was the best single variable to estimate mahogany age. The regression equation is as follows:

$$Y = 11.66 + 5.90X$$

where:

Y = age (number of growth rings) of mahogany (years).

X = basal diameter (centimeters).

The coefficient of determination (r^2) for this equation was 0.75. Additional variables were included, and the sample was partitioned by such factors as habitat type and aspect in further regression analysis; however, the r^2 improved only slightly. Consequently, the simpler regression equation was used to predict age.

Stand Age And Structure

Forty-one mahogany stands in 13 habitat types wer sampled (table 1). Stands were grouped into five categories by potential climax association and stand structure as follows:

Category 1. Mahogany is the potential climax. Stands are comprised of all age classes dating from pre-1830.

Category 2. Mahogany is the potential climax. Stands are almost entirely comprised of post-1900 age classes.

Category 3. Mahogany is seral. Conifers are present but scattered and not yet competitive.

Category 4. Mahogany is seral and is being replaced by conifers.

Category 5. Mahogany communities arising after post-1900 disturbances.

Analysis of stand age (categories 1 to 4) showed great increase in mahogany density during the pas 150 years (table 2). After 1940, the rate of increase accelerated (fig. 5). This rate is inflated because 11 of the 36 stands sampled were almost entirely comprised of young plants. The most noteworthy aspect of the data in figure 5 is that only 1 percent of the mahoganies in 1970 stands was present before 1830. We concluded tha the 1980's sampling provided a reasonably accurat picture of the pre-1830 stand because there was little evidence of plant losses after 1830.

Separate analysis of the five categories revealed differences in stand development. Stand data wer graphed to display changes in density over time.

Category 1 (All Aged Potential Climax Mahogany)

Historically, category 1 stands were protected from fire by rock outcrops or by discontinuous fuels. In 1855, some stands were lightly stocked (13 stems/acre; 31/ha), and a few stands were well stocked (203 to 329 stems/acre; 501 to 813/ha). Most stands regenerated after 1855. The rate of regeneration seems to have been strongly influenced by canopy coverage and competition from other plants. Closed canopy stands, such as Mountain City 2 (fig. 6), which

Table 1.--Characteristics of potential climax and seral mahogany stands in the five State study area

Stand	Habitat type	Parent material[1]	Aspect	Elevation	Slope	Average Cele cover	Evidence of past fires[2]
				---Feet---	-----Percent-----		
Category 1 (all aged potential climax mahogany)							
Riggins 1	Cele/Agsp	L	SSE	3,100	70	20	P
Riggins 2	Cele/Agsp	L	W	2,300	55	14	C
Riggins 4	Cele/Agsp	B	SW	2,200	32	31	C
Challis 3	Cele/Agsp	L	SSW	7,000	33	18	P
Bruneau 1	Artrva/Syor/Feid	B	SE	6,000	5	50	P
Bruneau 2	Artrva/Syor/Feid	B	N	6,100	8	15	P
Mountain City 2	Artva/Syor/Feid	B	WNW	6,500	7	49	N
Jarbridge 2[3]	Cele/Syor/Feid	R	W	7,600	46	69	P
Sawtooth 1	Artva/Syor/Feid	B	N	7,200	8	50	N
Bridger-Teton 1	Cele/Artva/Feid	S	W	7,800	35	29	P
Bridger-Teton 2	Cele/Artva/Feid	S	W	7,500	33	18	P
Ironrod 1	Cele/Agsp	G	W	6,200	26	38	N
Category 2 (young stands; mahogany potential climax)							
Riggins 3	Cele/Agsp	L	S	3,200	33	1	P
Challis 4	Artrva/Syor/Feid	L	ENE	7,500	47	55	P
Soda 2	Juos/Cele/Agsp	L	E	6,200	63	4	P
Bannock 1	Cele/Agsp	G	SW	6,200	47	23	N
Bannock 2	Pifl/Cele/Agsp	G	WSW	7,000	43	30	C
Melrose 1	Cele/Agsp	L	SW	6,300	32	11	N
Melrose 2	Cele/Agsp	L	WSW	6,300	18	16	N
Threeforks 1	Pifl/Cele/Agsp	L	NW	4,800	23	45	N
Threeforks 2	Pifl/Cele/Agsp	L	NW	4,800	25	25	N
Category 3 (seral mahogany with scattered conifers)							
Salmon 1	Pipo/Feid	G	SW	4,500	62	18	P
Salmon 3	Psme/Cele	G/L	S	4,600	62	21	P
Leadore	Pifl/Cele	L	W	7,500	42	24	P
Challis 5	Psme/Cele	L	NE	7,500	50	57	P
Jarbridge 1	Abla[5]	G	W	8,200	58	12	P
Sawtooth 2	Abla[5]	B	NW	7,100	14	59	N
Sawtooth 3	Pimo/Artrva/Agsp[5]	L	SE	8,000	26	31	N
Soda 1	Juos/Cele/Agsp[5]	L	S	6,200	39	40	N
Targhee 3	Psme/Syor	L	SW	6,300	51	19	P
Targhee 4	Pifl/Syor	L	SSE	7,200	52	57	P

See footnote at end of table.

continued

Table 1.--(continued)

Stand	Habitat type	Parent material[1]	Aspect	Elevation	Slope	Average Cele cover	Evidence of past fires[2]
				---Feet---	-----Percent-----		
Category 4 (seral mahogany with competitive conifers)							
Sawtooth 4	Pimo/Artrva/ Agsp[5]	L	S	7,500	35	8	N
Challis 1	Psme/Cele	L	N	8,000	5	34	N
Targhee 2	Psme/Syor	L	S	6,500	50	20	P
Greer Gulch	Psme/Cele	G	WSW	5,000	38	28	N
Category 5 (disturbed mahogany stands)							
Mtn. City 1	Artrva/ Syor/Feid	B	SW	6,500	20	6	Burned October 1975
Targhee 1	Psme/Syor	L	W	6,300	64	1	Burned 1966. Seeded to grass after fire
Challis 2	Cele/Agsp	L	SSW	7,000	35	1	Burned 1934. Very slow regeneration.
Salmon 2	Psme/Cele	G	W	4,800	64	37	Last burned in 1919.
Challis 6	Psme/Cele	L	NE	8,000	5	2	Timber harvested. Slash was piled and burned.
Soda 3[4]	Juos/Cele/ Agsp[5]	L	SE	6,200	46	20	Juniper had been cut for posts.

[1] B = basaltic; G = granitic; L = limestone; R = ryolite; S = sandstone.

[2] P = fire evidence present; C = circumstantial evidence present; N = no evidence of past fires.

[3] Sapling sized Abla establishing in former Cele stand.

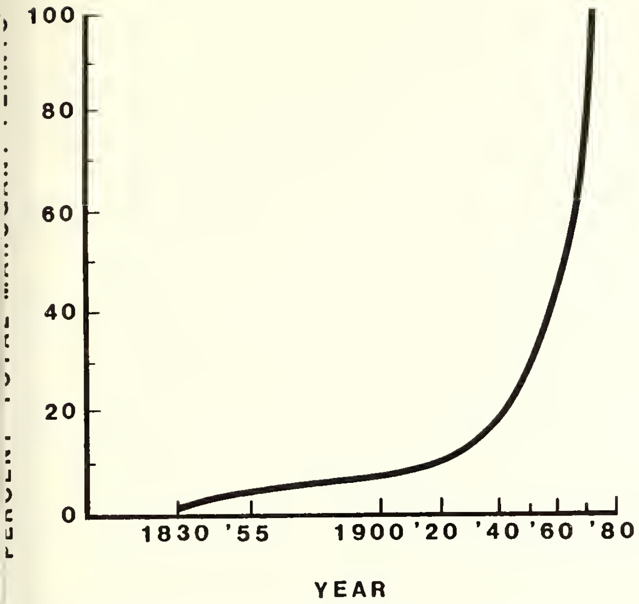
[4] Post-cutting estimated to have occurred 30 to 50 years ago.

[5] This vegetation has not been adequately habitat typed in this region, consequently this designation has been tentatively applied by the authors.

Table 2.--Summary of number mahogany stems per acre (stand density) by period of establishment for all stands except disturbance stands in category 5

	Period of establishment							
	Before 1830	1831-1855	1856-1900	1901-1920	1901-1940	1921-1950	1941-1960	1961 1970
Statistic[1]								
Median	0	26	26	51	76	51	51	51
High	89	253	177	405	759	2277	3138	4200
Low	0	0	0	0	0	0	0	0

[1] Median data were used in place of mean because extraordinary high values reflective of young stands in category 2 tended to skew the mean unreastically high as an (average).



igure 5.--Mountain mahogany densities in ategory 1-4 stands from 1830 to 1970. ercentage values for dates of record were alculated by dividing the number of stems per ecord date by the total number of stems in 1970. fter 1830 percentage values are accumulative.

egenerated mostly after 1900, show a significant ecline in regeneration since 1940. Shading, itter accumulation, and lack of bare soil pparently reduced the opportunity for seedling stablishment. Foraging on seedlings by domestic ivestock, deer, rabbits, and rodents may also be nhibiting regeneration. Stands with more open anopies and exposed bare soil such as Bruneau 2 ave been regenerating at a sustained rate (fig.). Less open stands (B-T-1) continued to egenerate but at a slower rate; whereas others Challis 3) have had a substantial increase in egeneration during the past 30 years (fig. 7). ccelerated rates of regeneration in recent ecades seem to be strongly influenced by stands eaching a critical reproductive age. When this oint is reached, seed is dropped and egeneration establishment takes place on suitable icrosites.

ategory 2 (Young Stands; Mahogany Potential limax)

hese stands occur typically on deep soils that istorically have had grass cover. Except for annock 2 (table 1), past fires were not evident. e believe that surface fires were once frequent nd completely consumed the light fuels, thus reventing the establishment of mahogany.

ome stands became established between 1900 and 920, and regeneration accelerated after 1940 fig. 8). Since about 1960, however, the rate of egeneration has sharply declined. Other stands, uch as Threeforks 1 (fig. 9), did not become stablished until about 1940. This stand has been egenerating rapidly in recent decades.

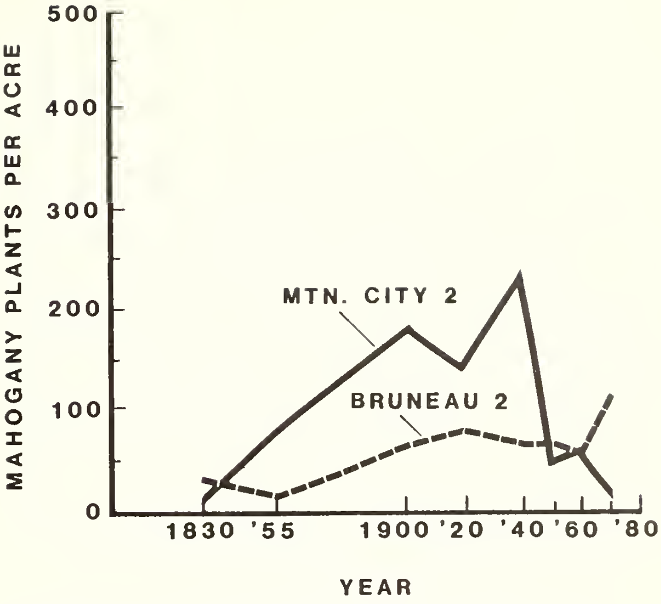


Figure 6.--Potential climax stands showing contrasts in reproduction. Mountain City 2 regenerated at an accelerated rate through about 1940 and then declined sharply. Bruneau 2 shows a lower rate of regeneration with an upturn since 1960.

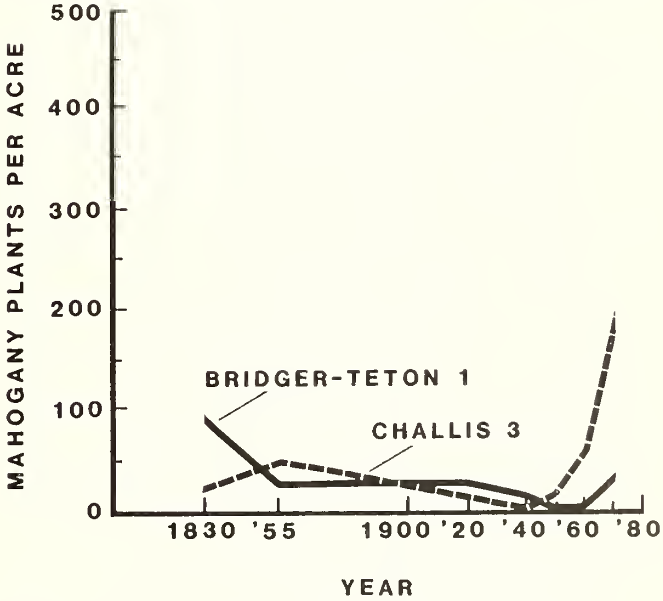


Figure 7.--Examples of potential climax stands that show differences in rates of regneration. Bridger-Teton 1 is an old stand that continues to regenerate at a low level. In contrast, Challis 3 shows accelerated regeneration during the past 30 years.

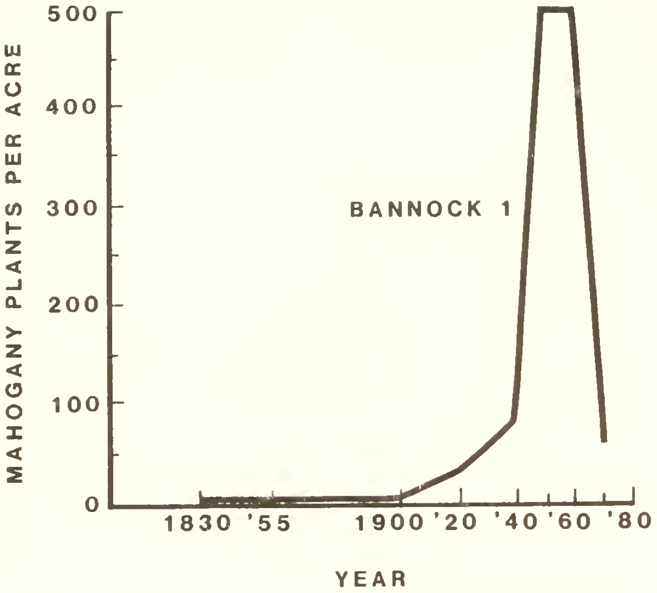


Figure 8.--Example of a potential climax stand in category 2 that regenerated on a site that was not occupied by mahogany prior to about 1920. Sharp decline in regeneration seems to be result of the site becoming fully stocked.

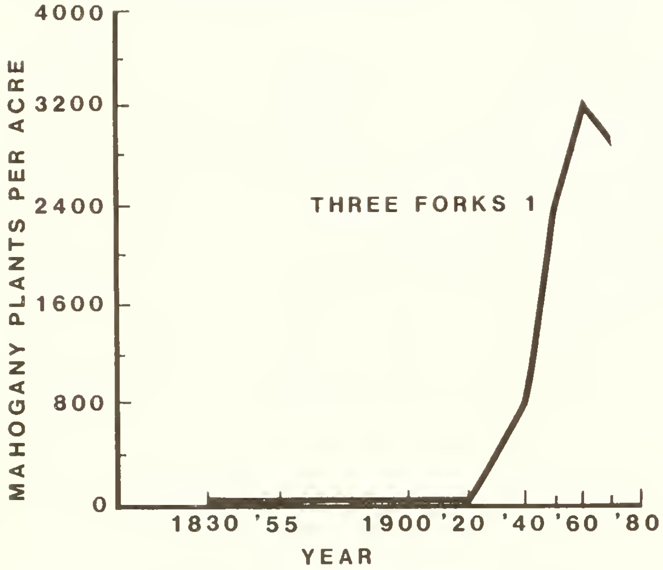


Figure 9.--Example of a potential climax stand that did not become established until about 1940.

Category 3 (Seral Mahogany With Scattered Conifers)

These stands are structurally similar to category 1 except that mahogany is seral. In regions of short fire intervals (mean intervals less than 30 years), fire suppressed conifers and kept the mahogany confined to rock outcrops or sites where sparse fuels did not allow fire to carry. Visual evidence suggests that when woody fuels had accumulated and burning conditions were extreme, fires killed portions of mahogany stands (fig. 2). In more moist communities, such as the Targhee 3 and 4 stands (table 1), infrequent severe fires killed conifers and mahogany over large areas.

Sawtooth 2 (fig. 10) is indicative of many stands having had a sustained increase in regeneration over the past 150 years. Most of the regeneration occurred after 1940. In contrast, other stands have had a marked reduction in regeneration. Regeneration on Targhee 3 (fig. 10) has declined markedly since 1920. Failure of some stands to regenerate seems to be influenced by closure of mahogany canopies and a marked reduction in conditions favorable for seedling establishment.

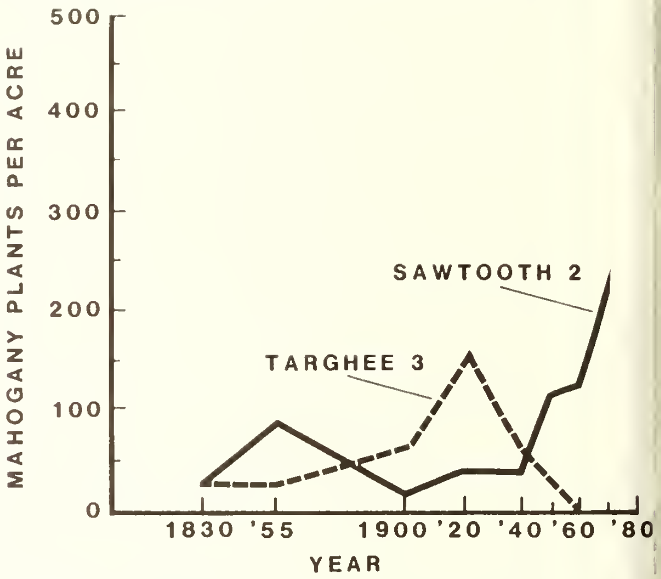
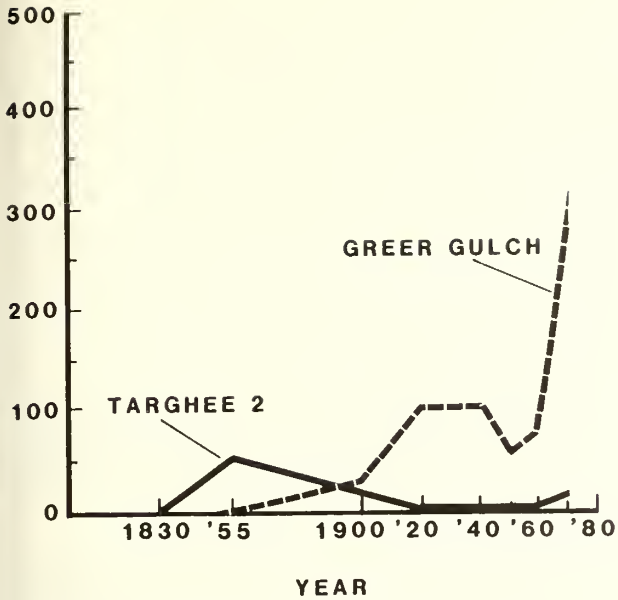


Figure 10.--Examples of seral mahogany stands in category 3 where conifers are not competitive. Sawtooth 2 shows accelerated regeneration after 1940, while regeneration on Targhee 3 has been on the decline or absent since 1920.

The trend in these stands has been a long-term increase in numbers of plants. During the past several decades, some stands have had increased regeneration; in others regeneration has subsided. Stands that contain old plants will become increasingly susceptible to fatal attacks by insects such as those described by Furniss and Barr (1975). Losses to insects and closure of conifer canopies will conceivably result in large-scale loss of mahogany.

Category 4 (Seral Mahogany With Competitive Conifers)

Many mahogany stands fall in this category; however, few met our criteria because the density of mahogany was too low to be included in the sampling. These stands vary most in age and stand structure. They frequently exhibit wide differences in the success of regeneration. For example, Targhee 2 had not regenerated successfully (except the 1970 age group) since about 1900 (fig. 11). In contrast, Greer Gulch (fig. 11) is almost entirely comprised of plants that regenerated post-1900. This stand is comparable to category 2 stands except for the presence of many conifers.



igure 11.--Examples of differences in egeneration in mahogany stands in category 4 here conifers are competitive. Targhee 2 shows irtually no regeneration in an established stand f conifers since about 1900. In contrast, the reer Gulch stand essentially regenerated since 900 and at a much higher level in a developing onifer stand.

ahogany in category 4 stands is being displaced y conifers. The level of competition varies from cattered conifers, beneath which are mahoganies low vigor, to closure of conifer crowns and hole-scale loss of mahogany. Without isturbance, the long-term prognosis for category stands is replacement of mahogany by conifers.

ategory 5 (Disturbed Mahogany Stands)

ands in this category were selected to determine e success of mahogany regeneration after isturbance. The time required for seedling stablishment varied considerably. The Mountain ity 1 stand (table 1) regenerated from seed llowing an October 21, 1975, fire that mpletely destroyed the parent stand. Over 4,000 edlings per acre older than 3 years were tallied 1982. Initial germination was from seeds of e 1975 crop that apparently had fallen to the ound or from seed banks stored in the litter. e likelihood of this quantity of seed having en transported from off-site sources is remote. mediate seedling establishment following fire s also measured at the Targhee 2 site (table 1). her examples of successful seedling tablishment following fire were noted. Only 2 rcent of the Mountain City 1 and 4 percent of e Targhee 1 stands regenerated from sprouting, ich was confined to plants between 20 and 30 ars old.

asurement of the Challis 2 site revealed delayed generation within the 1934 Pats Creek burn. The preburn stand was of low density, and the stand did not regenerate until about 30 years after the fire. All parent trees except those on outlying ridges and in rock outcrops were killed by a severe summer wildfire that apparently destroyed the on-site seed source. Subsequent failure of seedling establishment may have resulted from limited seed dispersal and the warm south-southwest aspect, where temperatures were excessively hot for seedling survival. Shading from sagebrush and other ground cover in later years may have provided suitable microsites for seedling germination. Initially, seed dispersal from off-site locations was apparently inadequate; however, scattered mahogany seedlings eventually established themselves. As on-site mahogany regeneration reached seed-bearing age, the rate of regeneration increased dramatically.

Immediate establishment of mahogany following cutting was recorded on two sites. A selection cut in dense Douglas-fir (Salmon 2, table 1) that contained scattered old-growth mahogany resulted in establishment of many mahogany seedlings. Vigorous seedlings were observed growing where the slash had been piled and burned. Before the timber harvest, mahogany had not regenerated successfully since 1900. Sampling at the Soda 3 site (table 1) also documented accelerated mahogany regeneration following the cutting of juniper for posts and poles.

Sampling in disturbed stands that were logged or burned indicated that a reduction in competition and an increase in exposed mineral soil enhanced successful seedling establishment. Observations of other logged and burned mahogany stands that were not sampled suggested comparable relationships. Quantitative data from this study showed that successful seedling establishment was closely linked to condition of the soil surface. Most seedlings were found on exposed mineral soil. No seedlings over 2 years old were found where litter exceeded 0.25 inches (6 mm) in depth.

Regeneration following disturbance can vary greatly depending on intensity of treatment and availability of seed crop. Fires in very small stands kill most mahogany, thus removing the seed source. In large stands, however, many plants survive because of discontinuous fuels. This "fire mosaic" treatment allows seeds to disperse from surviving plants into openings, thus increasing the probability of successful seedling regeneration.

MANAGEMENT IMPLICATIONS

Our data and observations show the desirability of excluding fire from many communities, especially sites where mahogany is the potential climax and where stands are 50 years of age or less. Burning would cause marked retrogression in these communities. There are, however, many low-vigor mahogany communities that would respond positively to fire.

Following are some considerations that may prove helpful in determining where it would be desirable to exclude fire and where there is a solid ecological rationale for using prescribed fire.

Potential Climax Mahogany Stands.--Vigorous stands are not candidates for prescribed fire. Many of these stands are young, having regenerated since 1920. Prescribed fire is also not recommended in stands with woody fuels such as sagebrush where mahogany is scattered or in stands of 0.5 acre (0.20 ha) or less.

Prescribed fire can benefit old mahogany stands that support sufficient fuels to carry fire. The best opportunities include localities where rocky outcrops and sparse fuels allow mahogany to survive as scattered individuals and in clumps. The chances of mahogany surviving and serving as cover and a seed source for immediate mahogany regeneration are enhanced as the burn becomes larger. A fall prescription including several thousand acres of burned and unburned areas would be ideal, especially where mahogany is associated with woody, crown-sprouting shrubs and trees.

Seral Mahogany Stands.--Prescribed fire is most likely to improve mahogany productivity in seral mahogany stands. The higher priorities are in category 4 stands, where conifers are competitive and mahoganies have not been reproducing for many decades. The objective of burning would be to kill competing conifers, remove other plant competition, and promote conditions conducive to seedling establishment.

The size of the burn would depend upon type of terrain, fuels, and the abundance of mahogany. In most instances a burn of several hundred acres would be advisable to avoid excessive browsing of seedlings by wild ungulates and livestock. In remote regions where wildlife values and livestock grazing are primary considerations, there are opportunities to use fall burning prescriptions and natural features of the terrain to execute prescribed burns of several thousand acres. These burns would result in differential burning by removing groups of mahogany where woody fuels were plentiful and leaving mahogany unharmed where woody fuels were sparse. Our observations suggest that mahogany stands will not carry fire unless there are sufficient surface fuels. Large treelike stands supporting grassy fuels and minimal litter usually survive the fire.

In some areas, old-growth mahogany is associated with patches of commercial-sized saw timber. In this circumstance, there is an opportunity to encourage new mahogany plants by making small block cuts of 0.50 to 2 acres (1.23 to 1.94 ha). Opening of the conifer canopy, mechanical disturbance, and prescribed fire used in slash cleanup can provide conditions that permit seeds to disseminate on exposed mineral soil and thus establish seedlings. Leaving several seed-producing mahoganies in openings increases the probability of successful regeneration provided grazing impacts are not excessive.

Fire management plans that include unscheduled (lightning or human) ignitions can be a useful tool in future management of mahogany. It is particularly apparent that there is little or no rationale for suppressing wildfires in localities where mahogany is being outcompeted by conifers. Prolonged fire suppression will continue to reduce the numbers of seed- producing plants and thus will markedly reduce recovery potential following a hot wildfire.

Prescribed fire to enhance the condition of mahogany should be considered on a case-by-case basis. Applying prescribed fire through planned or unscheduled ignitions has a place in mahogany management. We suggest that managers responsible for ecosystems that include mahogany strongly consider the consequences of continually protecting declining stands. The future viabilit of this important plant will depend on whether we take the short-term approach of protection or the long-term view that recognizes disturbance as essential in promoting productive mahogany stands

SUMMARY AND CONCLUSIONS

The combined quantitative and historical evidence strongly suggests that before European settlement fire significantly influenced mahogany in the Northern Rockies by restricting stand development A reduction of fire periodicity and size followin Euroamerican settlement apparently allowed mahogany seedlings to regenerate far in excess of former levels. The absence of fire for long periods has resulted in great variation in structure of mahogany stands. Many stands are declining because of losses to insects and conife competition. In other areas, vigorous young mahogany predominate. These wide differences in stand conditions suggest different management strategies are needed at the local level. Fire management strategies may be used to manage mahogany stands.

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MANAGING WILDLIFE HABITAT WITH FIRE IN THE ASPEN ECOSYSTEM

Norbert V. DeByle

BSTRACT: Much of the nearly 7 million acres 2.86 million ha) of aspen in the western United tates is seral to conifers. Also, most aspen tands are old, in excess of 60 years. Proper reatment of these aspen forests will retain the spen and can produce optimum wildlife habitat. ptimally, all age and size classes of aspen hould be present on the landscape. Fire is often e most economical and, ecologically, the most atural treatment applicable in the many acres of nmerchantable but burnable aspen community types the West. Fire of sufficient severity will ill the old stand, cause profuse aspen root ckering, and increase forage production. rrently, baseline data are being gathered for eveloping fire prescriptions and describing the els in Wyoming and Idaho aspen types. The fects of fire on the aspen plant community, specially on its value as wildlife habitat, is lso being assessed.

ITRODUCTION

the interior western United States there are ,067,200 acres (2 859 944 ha) of aspen (*Populus emuloides*). Of this, some 2,664,200 acres (1 8 163 ha) are noncommercial (Green and Van oser 1983). In addition, many millions of acres aspen occur in the western provinces of Canada d Alaska.

ldlife managers generally agree that the aspen rest type is especially valuable habitat for a riety of upland species of birds and mammals, th game and nongame (Gullion 1977b). In the terior West, aspen takes on a particularly portant role for wildlife, because it is the ly upland hardwood tree species and it equently is found in groves in the coniferous rests or as isolated stands in mountain asslands and shrublands. In the conifers, the pen groves may be the only source of abundant rage; in the grasslands they may be the sole urce of cover.

recently reviewed the literature and contacted veral sources to compile a listing of birds and mmals that occupy the aspen type in the West (DeByle in press). Some 134 species of birds and 55 species of wild mammals were included. Among the game birds, there are six species of ducks, two forest grouse (blue and ruffed), two pigeons (band-tailed and mourning dove), the sharp-tailed grouse, and the wild turkey (*Meleagris gallopavo*). Among the larger mammals, there are moose, elk, white-tailed deer, mule deer, snowshoe hare, cottontail rabbit (*Sylvilagus nuttallii*), bison (*Bison bison*), raccoon (*Procyon lotor*), mountain sheep (*Ovis canadensis*), mountain lion (*Felis concolor*), black and grizzly bears (*Ursus americanus and U. arctos*), and several furbearers.

Aspen is a seral forest type on the majority of sites. It is a relatively short-lived tree (about 100 to 125 years in the West) that readily gives way to longer lived and more shade-tolerant conifers. If a conifer seed source is present, the typical aspen stand responds approximately as shown in the model developed by Bartos and others (1983). Herb biomass peaks first, then shrubs (fig. 1). As long as aspen dominates, there is a large herbaceous or shrub biomass in the understory, but as conifers take over, this source of forage and low cover largely is lost.

Most of our western aspen stands have reached maturity because they have been protected from wildfire and have not been marketable for most of this century. In a Colorado survey, Shepperd (1981) measured an average age of 80 years, with stands younger than 50 years difficult to find. Single-aged stands predominated, but two-aged and all-aged stands were frequently found.

Treatments are needed to retain aspen on sites where it is seral. And, whether seral or not, treatments are needed if we wish to have a variety of aspen age and size classes represented on the landscape. In the natural setting, wildfire probably was the most common cause of widespread even-aged regeneration, although insect and disease outbreaks may have played a role, too. In the managed forest, clearcutting, herbicides, or prescribed fire may be used to effectively treat aspen stands by killing the overstory and triggering abundant aspen regeneration.

Aspen regenerates by producing root suckers in large numbers after the parent tree is top-killed. Such vegetative reproduction over several generations has produced a mosaic of aspen clones (groups of genetically identical stems) on the landscape (Barnes 1966). In the West, regeneration by seed is rare because a continuously moist, mineral soil seedbed is required throughout the first growing season (McDonough 1979).

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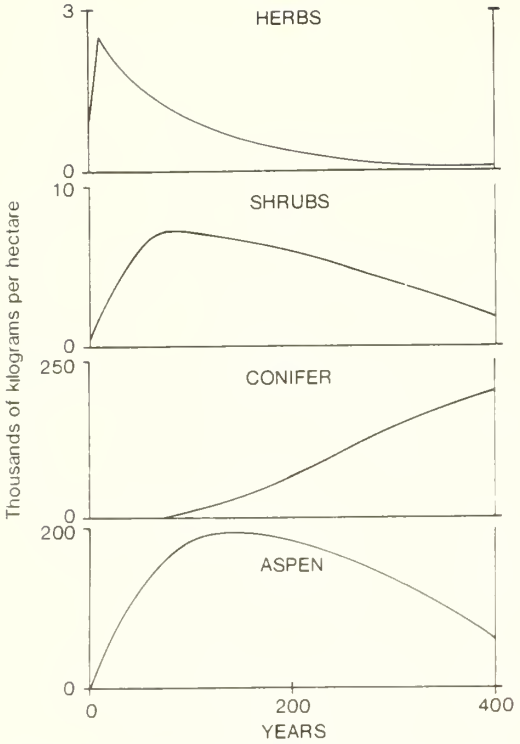

Figure 1.--Expected biomass of four vegetation components through time after a severe fire in aspen on a typical mesic site in the West. A conifer seed source is assumed. (From Bartos and others 1983, fig. 29a, p. 27.)

Sudden top-killing of an aspen stand upsets the hormone balance in the roots. Auxins, produced in tree crowns, are no longer supplied, and cytokinens, produced in roots, are no longer moved into the crowns. The lack of auxins, an increase in cytokinens, and warmer soil temperatures help stimulate abundant sucker production from roots near the soil surface (Schier 1981a, 1981b). If, say, the parent stand consisted of 200 stems per acre (494/ha), by the end of the second growing season after fire or clearcutting, there often will be some 40,000 suckers per acre (98 842/ha). Suckering response varies widely, due to genetic and site factors as well as the density of aspen roots near the soil surface. A good rule of thumb is 10,000 suckers per acre (24 710/ha) will produce a satisfactory forest stand--if roundwood products are being grown on the site.

The concern that high densities of young aspen will produce a stagnated stand is not justified because aspen is self-thinning. Disease, insects, browsing animals, snow breakage, and shading of these intolerant aspen suckers all take their toll. By maturity, a stand of 200 stems per acre (494/ha) again might be expected. During the 70- to 100-year interim, from a dense stand of young suckers to a mature stand of aspen trees, a progression of habitats will have been made available for a variety of wildlife species.

CASE STUDIES

There are many references in the literature about the effects of fire, usually wildfire, on aspen regeneration. There are far fewer on the effects on wildlife populations, and many of these are somewhat speculative. Usually the effects on plant communities are measured and the effects on associated wildlife are inferred.

Scotter (1972) points out that fire is at least partly responsible for maintaining extensive stands of aspen and other seral species in the boreal forest region but that the influence of fire on the animals cannot be easily evaluated--some members are benefited while other are disadvantaged. For optimum elk or moose habitat, both Gruell and Loope (1974) and Spencer and Hakala (1964) describe the benefits of fire i the aspen type. In the North, both Lutz (1956) and Viereck (1973) feel that fire may be deleterious on caribou (*Rangifer tarandus*) winter range because fire destroys lichens; on the other hand, it benefits moose and snowshoe hares becaus they depend upon the successional plant communities, notably aspen, that are produced. Much further south, Patton and Avant (1970) found that fire is an effective tool for producing deer and elk browse in the mixed aspen-conifer forests of New Mexico.

Those animal species that depend upon the forage or cover produced in a young aspen community will benefit from fire. They include some of the more important (game) species of wildlife--moose, elk, deer, ruffed grouse, and snowshoe hare. Others may do well in old, sometimes derelict, aspen stands--cavity-nesting birds for example. For these, fire is not necessary for habitat management if the aspen on the site is stable or climax. Other species of wildlife, such as red-backed voles (*Clethrionomys gapperi*), red squirrels (*Tamiasciurus hudsonicus*), and pine martens (*Mustela americana*), do best in coniferou forests. Fire to set back succession and retain aspen will be deleterious for these species. If diversity of habitats and a diversity of wildlife species are wanted, fire can play an important role in maintaining the mosaic of plant communities and age-size classes within these communities on the overall landscape. If edge is wanted, fire again is a tool to provide maximum edge between the patches in this mosaic. Thus, w must be specific what we want before prescribing fire or any other treatment.

The Role of Fire in Habitat Management of a Few Key Species

Elk.--The wapiti, or elk (*Cervus elaphus*), are grazing animals that prefer grassland, shrubland, and recent burns over the mixed forest community (Rounds 1981). They choose aspen over coniferous communities in summer and winter (Ackerman and others 1983), although conifers may be used for hiding (security) and thermal cover during times of harassment or severe weather (Thomas 1979).

Elk prefer grasses, then forbs; as curing or loss of herbaceous material occurs, they use deciduous browse species first and coniferous browse last. Aspen is avidly sought from among the browse species (Kufeld 1973; Nelson and Leege 1982). The aspen suckers themselves, however, will extend their crowns above the reach of elk in 6 to 8 years if growing in the open and not browsed (Patton and Jones 1977). In summer, the combined values of good forage and cover in the aspen forest make it especially valuable to elk; at this time they may select aspen stands over adjacent clearcut areas that have even more palatable forage (Collins and Urness 1983).

To provide optimum habitat for elk, Thomas (1979) recommended that 60 percent of the land area be managed to provide forage. Good forage is provided by the herbaceous and shrubby understory in the aspen as well as by aspen suckers less than -1/2 ft (2 m) tall. Peak production of this component is reached within a few years after burning (Bartos and others 1983).

n the Jackson Hole area of western Wyoming a ombination of factors is causing the demise of spen on big game winter ranges. Fire protection as permitted large areas of aspen to reach aturity and to begin the successional process oward conifers (Gruell and Loope 1974; Gruell 979), and concentrations of big game, especially elk near winter feedgrounds, in some instances are ating every sucker that arises (Beetle 1979; einstein 1979). If nothing is done, aspen over arge areas will disappear within a century Krebill 1972). If protection can be provided rom browsing elk (DeByle 1979), then fire can be sed to regenerate the declining aspen stands. omewhat similar conditions occur in and near ocky Mountain National Park in Colorado (Olmstead 979).

n recent years fire has been used on an xperimental basis in the Jackson Hole area Bartos 1979; Bartos and Mueggler 1979, 1981). hey found that understory production decreased in he first postburn year, then increased to well ver that on the unburned sites in the second and hird postburn growing seasons. On one site in he second year there were 3,211 lb/acre (3 600 g/ha) produced, about double that found before urning. Most of this was fireweed (*Epilobium ngustifolium*)--a species palatable to cattle and lk. Production of aspen suckers was greatly ncreased by burning, enough to replace the parent tand where browsing pressure is not too great. n the sites where elk browsing pressure was reatest, there were 5,665 to 8,094 suckers per cre (14 000 to 20 000/ha) present in the eclining aspen stands before burning; this ensity nearly doubled in the second postburn ear, but by the end of the third postburn year, ucker densities had returned to near preburn evels (Bartos and Mueggler 1979, 1981). Even hough over 1,000 acres (405 ha) was burned, elk se of aspen was deterred only one winter. Elk rowsing the third winter averaged 44 percent of urrent annual growth and eliminated the height rowth from the previous summer (Basile 1979). Under current browsing pressures on heavily used areas, the small increase in sucker numbers after burning is not expected to regenerate these aspen stands.

Moose.--The largest member of the deer family, the moose (*Alces alces*), extensively uses the aspen ecosystem. They are primarily browsers, especially in winter (Peek 1974). Forbs are also extensively used when available in spring and summer. Usually moose first select willow (*Salix* spp.) and then aspen as browse. The typical understory forbs and shrubs in the aspen type as well as young aspen are favorite moose forage.

Moose can utilize larger saplings than can deer or elk. Their height of reach is 8 ft (2.4 m), and they will break down saplings up to 4 inches (10 cm) in diameter to reach higher browse (Telfer and Cairns 1978).

Moose have a high tolerance for cold; they will occupy willow bottoms without much thermal cover early in winter. As winter progresses and snowpacks deepen, however, they move into densely forested uplands with less snow (Rolley and Keith 1980). Moose in Alberta selected aspen stands less than 33 ft (10 m) tall as preferred habitat (Rolley and Keith 1980). In Montana, Gordon (1976) described ideal upland moose habitat as having a good distribution of aspen and associated trees and shrubs in a mosaic of age classes. Conifer patches for hiding cover also are desirable, perhaps essential.

In Minnesota, Irwin (1975) found that moose selected deciduous forest stands, especially postburn communities that produce large amounts of preferred forage, during the summer-fall period. Willows and the sprouts of aspen, birch (*Betula* spp.), and maple (*Acer* spp.) were the most important browse species used.

Seral aspen being replaced by conifers in south-central Montana were burned to enhance winter moose habitat (Gordon 1976). Aspen suckers increased to 27,400 per acre (67 700/ha). After the second growing season they averaged 3 ft (91 cm) tall, and both they and willow sprouts could be utilized. Gordon found that the heaviest use of aspen and shrubs was adjacent to the unburned area, where cover was quite dense.

From work done in Alaska (LeResche and others 1974), Minnesota (Irwin 1975), Wyoming (Gruell 1980), and elsewhere (Gullion 1977b) it is evident that regeneration of young vigorous stands of aspen, willow, and associated shrubs, usually after fires, improves moose habitat and results in a moose population increase. After this browse grows out of reach, the moose population drops. LeResche and others (1974) noted that fire-induced seral communities in Alaska have the greatest moose densities.

Deer.--Mule and white-tailed deer (*Odocoileus hemionus and O. virginianus*, respectively) are common throughout the range of aspen in the West.

The mule deer predominates in the States with the most aspen. Deer herds in these States are migratory--they spend summers at high elevations within the aspen zone and winters on steppe and brushlands at lower elevations, usually below the aspen. Thus aspen is largely summer and fall range for deer in the West. During these seasons both thermal and hiding cover are abundant in the aspen type. Leckenby and others (1982) rated aspen communities on the shrub-steppe western range second only to riparian zones in value to mule deer. Deer prefer to feed in the aspen forest rather than in forage-rich clearcut openings, and they commonly bed down in the aspen forest as well (Collins and Urness 1983).

In spring and early summer deer prefer herbaceous forage, primarily forbs. As these cure, deer shift increasingly to browse; by winter their diets are three-fourths browse (Kufeld and others 1973). Aspen is among the top eight species of preferred browse for mule deer. Hungerford (1970) noted that aspen sprouts became a key food only after new growth matured, usually in July. Upon leaf fall in autumn, deer consume large quantities of aspen leaves (Julander 1952). In addition to the aspen itself, deer forage upon many of the common understory shrubs (snowberry, serviceberry, barberry, pachistima, chokecherry, rose, willow) and forbs (yarrow, aster, milkvetch, fleabane, geranium, peavine, lupine, knotweed, cinquefoil, dandelion, valerian, vetch) in the aspen forest type (Collins 1979; Kufeld and others 1973).

The impact of deer on aspen regeneration can be greatest in late summer and autumn. They will readily take young, succulent aspen sprouts on recent burns and clearcuts. They also browse on aspen up to a 5-ft (1.5-m) height, and therefore can have a significant impact on aspen suckers younger than 4 or 5 years or those suppressed by browsing to heights of less than 5 ft. Mueggler and Bartos (1977) noted that deer browsing prevented aspen regeneration in small clearcuts and in the uncut aspen forest, but nearby large burned areas regenerated successfully. They felt that burns or clearcuts less than about 5 acres (2 ha) would concentrate deer use and would be less likely to successfully regenerate than would larger areas.

Deer on their summer range will benefit from having plenty of aspen habitat available, especially if it contains an abundance of understory forbs and shrubs. Since both aspen suckers and the aspen understory are in greatest abundance within a few years after burning (Bartos and others 1983), it appears that management to provide an array of aspen age classes on the range would provide the best overall habitat. The burn units should be of adequate size, however, to prevent overbrowsing of the aspen regeneration. Perhaps 10- to 40-acre (4- to 16-ha) units burned or clearcut at intervals of 40 to 80 years would provide optimum deer habitat.

Snowshoe hares.--Snowshoe hares (*Lepus americanus*) are present throughout much of the aspen range in the West; however, they are more common in the associated coniferous forest types. In the Rock Mountains, winter hare habitat is lacking in mos pure aspen stands due to deep snowpacks. In northern Utah, Wolfe and others (1982) found 85 percent of winter use by hares was in vegetation types that had cover densities of at least 40 percent immediately above the snowpack. Sometim aspen with a very dense understory of tall shrub fits this criterion, but usually only conifers provide this much winter cover.

During the summer growing season, snowshoe hares disperse somewhat from coniferous winter cover (Wolff 1980). The aspen type then provides adequate cover and excellent forage. Aspen is nutritious and choice food for hares (Walski and Mautz 1977), although new suckers may not be as palatable as twigs on the mature growth because their high terpene and resin contents (Bryant 1981). In Alberta, Pease and others (1979) foun aspen to be among the six most common browse species. During summer the hares shift largely a diet of succulent plant material (Wolff 1980). Since the aspen type has much more herbaceous an shrub cover than most coniferous types, in summe it probably is the more desirable habitat.

The aspen type, if well interspersed with dense conifer patches, provides adequate snowshoe hare habitat in the West. Marginal habitat is provid with aspen and a dense understory of tall shrubs if this understory is not covered with deep wint snowpacks. It is doubtful that even the peak density of aspen suckers and shrubs on most aspe burns or clearcuts in the West provides adequate snowshoe hare habitat in winter (Wolfe and other 1982). Perhaps the best recommendation for management is one developed in Michigan (Conroy and others 1979), where clearcuttings managed fo hares were recommended as small and shaped so adequate canopy cover remained within 200 to 400 yards (about 200 to 400 m) of all parts of the opening. In the western United States and adjacent Canada, perhaps small irregularly shape clearcuts or burns and encouragement of small bu dense conifer patches throughout the aspen fores will provide maximum snowshoe hare habitat in th aspen type.

Ruffed grouse.--The ruffed grouse (*Bonasa umbell*) has a wide range across North America (Aldrich 1963), is associated with hardwood and hardwood-conifer mixed forests, and is primarily a bird o the aspen and associated forest types. Gullion (1977a) opined that there is an obligatory relat n-ship between ruffed grouse and the aspen type wherever snow covers the ground between November and April. Aspen is heavily used as food and as cover; it provides a highly nutritious food sour (Gullion and Svoboda 1972), protection from the weather (Bump and others 1947), and escape from predation (Gullion and others 1962). Wherever aspen and grouse ranges overlap in the West, the grouse selects aspen habitat during part or all the year, as shown by Phillips (1964, 1967) and Landry (1982) in Utah, Stauffer and Peterson (19) in Idaho, and Rusch and Keith (1971) and Doerr a others (1974) in Alberta.

Management for optimum ruffed grouse habitat must center on the aspen ecosystem and nearby dense, brushy vegetation. For Idaho and Utah conditions, Stauffer and Peterson (1982) recommended a diversity of habitat structure within 40- to 50-acre (16- to 20-ha) units. Drumming (breeding) sites should have 200 to 450 trees per acre (about 450 to 1 100/ha) that provide 80 to 95 percent tree cover and at least 2,500 small stems (shrubs and aspen sprouts) per acre (about 6 000/ha). Hens with broods prefer 50 to 75 percent tree cover, about 600 to 2,800 small stems per acre (1 500 to 7 000/ha), and openings with abundant herbaceous cover more than 20 inches (about 50 cm) tall. Winter cover should have large mature aspen for food and perhaps some conifers for cover. For Minnesota conditions, Gullion (1977a) recommended practices that maintain heavily stocked, fast-growing aspen stands in a variety of age (size) classes within the daily range of grouse. The value of conifers was questioned because they harbor avian predators. Stauffer and Peterson (1982) and Landry (1982) both emphasized the importance of a dense shrub layer in aspen or mixed aspen stands for our western conditions.

Even-aged management of 10-acre (4-ha) units on rotations of about 60 years perhaps will produce the best ruffed grouse habitat in the montane West. One unit should be treated (burned or clearcut) every 15 years within each 40- to 50-acre block, thus producing the diversity of habitat needed within the range of individual grouse. Clearcutting units as small as 10 acres is the most feasible treatment; then burning within a year afterward may provide the best brood habitat (Sharp 1970). Larger areas that are being taken over by conifers may be burned to set back succession, then later put into the rotation system of small 10-acre units (Stauffer and Peterson 1982).

Sharp-tailed grouse.--The sharp-tailed grouse (*Tympanuchus phasianellus*) in the parklands aspen habitat will use aspen trees in the winter and spring, but they prefer and select grassland and grassland-low shrub cover throughout most of the ear. During winter, small aspen and shrubs offer harp-tailed grouse protective cover and food. The grouse feed on aspen buds in winter and spring Hamerstrom 1963; Moyles 1981). Aspen is useful s small thickets of young growth (3 to 6 ft or 1 to 2 m tall) and as larger patches of taller trees or winter use (Evans 1968; Hamerstrom 1963). During much of the year, aspen, except as a shrub, eems to be of little or no importance and is perhaps even a detriment to the sharp-tailed grouse. The presence of aspen near breeding arenas discourages use by these grouse (Moyles 1981). Moyles cites evidence that invasion of grassland by aspen reduces sharp-tail habitat.

It appears that the sharp-tail is a bird haracteristic of early successional stages in the aspen ecosystem. Sharp-tails use frequently urned areas in which aspen regeneration is mostly shrub-size except for some scattered stands of mature trees that have escaped the fires. As extensive stands of trees return to this setting, the sharp-tail gives way to the ruffed grouse. Fire in relatively short intervals, say 20 years, could be used for management of sharp-tail grouse habitat. Large units of several hundred acres could be burned if patches of large aspen trees were protected.

OUR CURRENT RESEARCH

In 1981 the Intermountain Forest and Range Experiment Station commenced a prescribed fire study in the aspen on the Bridger-Teton and Caribou National Forests in western Wyoming and southern Idaho, respectively. There are two primary objectives: (1) to develop prescriptions for the use of fire to regenerate aspen and (2) to determine postfire plant succession and production. The research focuses on aspen sites that are being invaded by conifers or are susceptible to such invasion. Facets of the study include:

1. Probabilities of achieving weather conditions meeting specific prescribed fire conditions.

2. A method for predicting water contents of live herbaceous fuels.

3. A classification within the aspen ecosystem of fuels and their flammability.

4. The relation of overstory tree mortality to fire severity as evidenced by visible bole damage and fuel consumption.

5. The relation of aspen sucker populations to overstory mortality.

6. Vegetation response to fire, both with and without postburn grazing.

Adjunct to this research are two cooperative studies being conducted by Utah State University and the Intermountain Station. In the first study, forage quality is being assessed for several plant species on burned and unburned aspen sites during the first and second years after prescribed fire. In the second study, tame elk are being used to determine habitat selection, foraging behavior, and dietary nutrition during the second and third postburn years on burned sites and in the surrounding habitat.

A progress report that covered all facets of the primary study was given at the end of the 1982 field season (Brown and DeByle 1982). Research continues; however, data gathering and analyses for predicting fire weather (facet 1), for estimating water contents of live fuels (facet 2), and for developing a fuel classification (facet 3) are essentially complete. The fuel classification scheme was outlined by Simmerman (1983) and will be expanded into a more definitive publication in the near future. The results from the cooperative studies, when combined with the results from facets 4 and 5, should be of considerable interest to managers of wild ungulate habitats.

On most of the mid- to high-elevation aspen range in the West, the deep snowpacks do not melt away until spring greenup. Spring burning is not possible under these conditions, hence, we concentrated on developing prescriptions for autumn burns. Summer generally is dry in northern Utah, southern Idaho, and Wyoming. Fuels cure through late summer and autumn. As autumn approaches, the probability of major precipitation from a frontal storm system increases. To predict the probabilities of such storm systems, we analyzed the long-term weather records for several stations. Two prediction lines are shown in figure 2. The solid line represents the accumulative frequency of a storm that temporarily prevents burning; subsequent drying, however, would return prescribed burning conditions that season. The dotted line essentially predicts the end of the burning season. For example: in half of the years a frontal storm that delays burning for several days can be expected by mid-September, and the burning season will end, probably with a snowstorm, by approximately October 25.

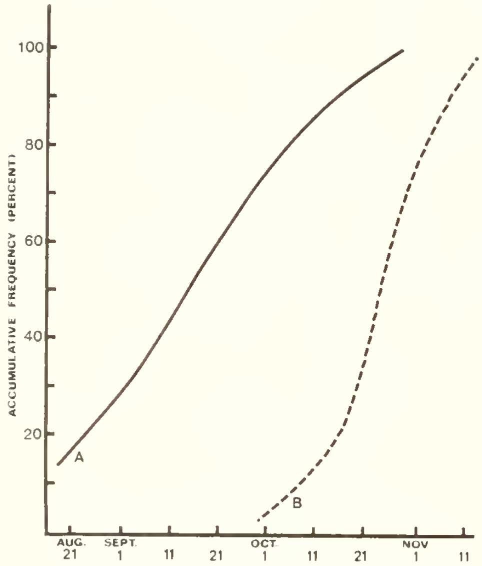

Figure 2.--Cumulative frequency curves of estimated dates before first major interruption of the prescribed burning season (curve A) and the last date of the prescribed burning season (curve B).

Fuel classification in the aspen ecosystem is based primarily upon understory characteristics (community types) and, to a lesser extent, upon successional status, amount of downed woody fuels, and grazing. Some of the major classes and their potential for prescribed burning are:

Overstory	Understory	Potential for prescribed fire
Aspen	Shrub	Good
Aspen/conifer mix	Shrub	Good
Aspen	Tall forb	Fair
Aspen	Shrub (grazed)	Fair
Aspen/conifer mix	Forb	Fair
Aspen	Low forb	Poor
Aspen	Tall forb (grazed)	Poor

NEEDS

It is generally accepted that managing western wildlands to provide an optimum amount of aspen on the landscape will benefit some key species of wildlife. It is generally accepted that managing this aspen to provide an array of age and size classes, perhaps in even-aged units of a few acres each will provide the best habitat for these key wildlife species. For most wildlife species, however, far too little is known about habitat needs to do a top-quality job of intensive aspen management to produce optimum habitat.

Several key wildlife species for which habitat management in the aspen type could be important have been used as examples in this paper. It is apparent that moose, elk, deer, snowshoe hare, and ruffed grouse will benefit by having an optimum amount of aspen in a variety of size classes on their range. Just how much is needed in relation to the mix and juxtaposition of other habitats is not known. For some species in some environments, aspen perhaps is all that is needed--an example is ruffed grouse in northern Minnesota (Gullion 1977a). For others, such as snowshoe hares in the montane West (Wolfe and others 1982), aspen alone will not provide satisfactory habitat. For still other species, aspen forest plus some other habitat variable is needed. Beavers (*Castor canadensis*), for example, use aspen (or willow) along streams and rivers. In addition, many species are migratory, such as most passerine birds, and use the aspen forest only during part of the year, but often during the all-important breeding season. These species are equally dependent upon habitats elsewhere for their year-round welfare. Manipulating the aspen type will not provide optimum habitat for this total mix of wildlife species.

Wildlife managers first must choose what key wildlife species are to be encouraged. Then they must determine what those species habitat needs are. Habitat needs must not be confused with preferences for some particular habitat components; instead, focus must be kept on what each species requires to maintain health, vigor, and an acceptable rate of reproduction (Peek and others 1982). The managers also must ascertain what the trade-offs are--what wildlife species are going to be placed in a disadvantageous position through some particular habitat management strategy. This is a difficult job, perhaps impossible with our present level of knowledge of habitat requirements for many species.

If the chosen key wildlife species are deer, elk, and moose (they usually are in the montane forested habitats of the West), perhaps enough is known about their preferences and some of their needs to make reasonable habitat management recommendations. Aspen clearly is preferred by these ungulates. On most of their ranges, aspen should be encouraged. A mix of habitats, consisting of mountain brush, meadows, conifers, and aspen may be best, but the proportions can only be speculated upon. Aspen on up to one-half of the range of these ungulates is perhaps most cceptable. Management of this aspen in even-aged nits of 5 to 60 acres (2 to 24 ha) each on a otation of 60 to 100 years will probably supply he greatest variety of habitats within the aspen ype and will ensure a considerable amount of dge around these units. With this management trategy, fire becomes a feasible option for illing 60- to 100-year-old aspen stands, at least hose with a shrubby understory, thereby riggering abundant even-aged aspen regeneration.

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MODELING SHRUB SUCCESSION FOLLOWING CLEARCUTTING AND BROADCAST BURNING

Penelope Morgan and L. F. Neuenschwander

BSTRACT: This conceptual model of early seral hrub succession following clearcutting and roadcast burning synthesizes ideas from previous esearch and modeling approaches into a simple iagrammatic model of the critical successional nfluences and processes. Illustrative examples re drawn from observations of successional evelopment following high-and low-severity burns n the *Thuja plicata/Clintonia uniflora* habitat ype in northern Idaho.

NTRODUCTION

he general trend in the study of succession ollowing fire is from natural history descriptions o quantitative models that yield predictions of ommunity development. The study of shrub uccession in northern Idaho is a typical example.

arly seral shrub development following fire in the oist cedar-hemlock forests of northern Idaho was escribed by Leiberg (1900) and has since been udied in detail by Mueggler (1965), Lyon and ickney (1976), and others. Shrubs rapidly invade rned areas and may dominate a site for many years ueggler 1965). Large-scale fires in the early 00's created many shrubfields that provided undant browse for big game. This prompted many udies, particularly of the shrub species portant for big game forage. Early descriptions succession following fire were general, seldom antitative, often limited to one or two species, d usually poorly documented. Information useful drawing a cohesive understanding of the factors fecting shrub succession is therefore often attered, unpublished, incomplete, or otherwise available.

isting models that predict change in forest derstory communities are often unsatisfactory to et more than the specific needs for which they re developed. The goal of this report is to view some of these models and their limitations d to present a general conceptual model for early rub succession.

Development of our model draws heavily on the previous work of Lyon and Stickney (1976), the existing literature, and our documentation of shrub succession following clearcutting and broadcast burning. We have been studying shrub succession following clearcutting and burning of dense coniferous forests on the *Thuja plicata/Clintonia uniflora* habitat type (Cooper and others 1983) in northern Idaho. Here, early seral communities are often dominated by shrubs that establish themselves immediately following fire. Native forbs and grasses do not have the potential to dominate the site and the forb/grass stage of succession is short lived. Forbs are common, and grasses are uncommon in this habitat type. More than 30 different shrub species grow on the habitat type, many of which are critical to timber and wildlife resource management.

We are building a simulation model based on the conceptual model presented here. The simulation model will predict regeneration, establishment, and subsequent changes in species composition in the early seral shrub communities that develop following high- and low-severity burns.

Ecological impact of fire on understory vegetation depends on burn severity. Severity is a function of the total fuel consumed by fire, a reflection of both total heat produced and duration of heating of the soil surface. We evaluated burn severity using visual criteria based on litter and duff consumption, evidence of mineral soil alteration due to heating, and size and depth of char on large woody fuels remaining after the burn. These criteria are similar to those developed for depth of char (Ryan and Noste, in press) and depth of burn (Rowe 1983). Burn severity may be unrelated to fire intensity. Fire intensity refers to maximum above-ground heat pulse and principally depends on consumption of fine fuels. In contrast, the degree of soil heating depends on consumption of duff and large woody fuels. Burn severity affects response of understory species and cambial damage to tree boles and roots more than fire intensity does.

PREVIOUS MODELS

Most existing forest successional models include only trees. If understory vegetation is considered, it is only by general growth form (Shugart and West 1980). The model of Bartos and other (1983) is a good example. Understory development affects aspen and conifer succession in

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this model; however, all understory species are grouped into shrub and herb components. More detailed descriptions of understory successional dynamics are needed in many disciplines. These descriptions should include changes in community structure, species composition, and growth rates of important understory species (Pfister 1982).

The stand prognosis model (Stage 1973; Wykoff and others 1982) predicts forest vegetation development following stand disturbance. It applies primarily to trees, but one can predict percent canopy cover, biomass, and height of some important understory shrub and grass species. The predictions are based on regression equations developed by Irwin and Peek (1979). Extensions to the model are being developed to predict total shrub cover, probability of establishment, percent canopy cover, and height of 42 shrub species (Laursen 1984). The regression equations were developed from empirical data collected in various forest habitat types and stand ages under different site conditions, tree stand densities, and types of disturbance (Stage 1973; Wykoff and others 1982). The regression approach is fairly easy to use as it does not require inclusion of mechanistic relationships, but it is data intensive. Predictions may have limited reliability for stand conditions, areas, or treatments other than those included in the original data base. The stand prognosis model does not consider the influences of severity of fire disturbance or existing understory vegetation on successional development.

The forest habitat type classification system provides a common means of stratifying the physical environment and is, therefore, a logical framework for studying secondary succession (Arno 1982). The secondary succession classification systems being developed by Arno and Simmerman (1982) and Steele (Steele and Geier-Hayes 1982) are diagrammatic models of tree and understory succession on selected habitat types in Montana and Idaho. Both approaches allow for different pathways of successional development depending on the nature of disturbance and initial stand conditions. However, neither is quantitative and neither identifies causal factors of observed successional patterns.

Recent descriptions of succession emphasize the influence of initial stand and site conditions, nature of disturbance, and life history characteristics of individual species as determinants of the multiple pathways of succession following disturbance. These include models based on the vital attribute concept of Noble and Slatyer (1980), and the JABOWA model (Botkin and others 1972) and its derivatives.

Vital attributes are those life history characteristics of a species that determine disturbance response. They include means of arrival and persistence, establishment, and timing of critical life stages (Noble and Slatyer 1980). The approach provides a conceptual framework for predicting response of individual species to disturbance based on general ecological and morphological characteristics. These characteristics are known for many understory species for which more detailed autecological dat are unavailable. Local applications have been to trees only, including models of tree succession following fire in Glacier National Park (Cattelin and others 1979) and some forest communities in Montana (Kessell and Potter 1980). Multiple pathways of succession depend on vegetation existing before disturbance and the fire return interval. These and other vital attribute models (Noble and Slatyer 1980; Noble 1981) are diagrammatic, but the approach need not be limite to nonquantitative applications. Kessel and Pott (1980) provided general predictions of abundance for common understory species.

JABOWA and its derivatives are forest gap regeneration models (Shugart and West 1980). Predictions of regeneration, establishment and changing species composition of trees through tim are stochastic. Life history characteristics of individual species determine successional development. Despite simplistic representations growth and competition, the models have been successfully adapted to many forest ecosystems an a variety of disturbances (Shugart and others 1981). This illustrates the importance of recognizing the influence of disturbance, existin vegetation, and individual species characteristic on the major processes of regeneration and establishment. The models do not include understory species or effect of severity of disturbance.

The BRIND model (Shugart and Noble 1981) predicts successional dynamics following fire in Australia forests. It is derived from JABOWA but differs b including fire intensity effects on tree regeneration and mortality. Fire kills trees directly by scorching crowns or increasing susceptibility to other sources of tree mortality in the model. Germination of tree seeds is enhanced or stimulated by fire depending on fire intensity. This model thus recognizes that not al fires have the same ecological impact on ecosystems. Although fire intensity and severity both affect fire damage of trees, severity would a better indicator of seed germination effects a some of the tree mortality factors. Species characteristics are important in the model, but the vital attribute approach is not specifically incorporated in the BRIND model.

Two particularly useful conceptual models applicable to shrub succession are those of MacMahon (1980, 1981), developed as a general mo of succession, and Lyon and Stickney (1976), developed to describe succession following north Rocky Mountain wildfires. Both emphasize the importance of on- and off-site propagule sources the processes of survival, dissemination, and establishment; and the importance of individual species characteristics as determinants of the pattern of successional development.

The variety of modeling approaches reflects recognition of need for predictions of early succession following forest disturbance (Pfister 1982; Franklin 1982), yet few theories have been advanced to describe the causes of early ccessional patterns (Zamora 1982). Modeling of rly succession in forests has been largely oided due to its apparent complexity. Large mbers of species are involved, autecological data r even the most important species are often cking, and species exhibit a wide array of fe-cycle strategies (Zamora 1982). Few models of derstory succession exist, as there is a belief at once communities reach the forest stage, the quence of successional events becomes more edictable.

rly succession is neither too complex nor too riable to defy prediction. Previous research and deling attempts have identified critical ccessional influences and useful approaches to ndling them in a modeling context. Identifying itical life history characteristics of ccessional species (Gill 1977, 1981; Naveh 1975; ble and Slatyer 1980; Rowe 1983); stratifying vironments by habitat type (Arno 1982; Arno and mmerman 1982; Stage 1973); and describing fferential species response to burn severity owe 1983) provide means to reduce variability and low prediction. Availability of these ideas has eatly simplified our conceptual development to e of synthesis. We have combined the best aracteristics of previous research and modeling proaches into a simple conceptual model of shrub ccession following clearcutting and burning.

CNCEPTUAL MODEL

r model of early succession (fig. 1) is briefly tlined in an overall description of the linkage major successional processes and influences. re detailed treatment of successional processes cluded in the model follows in subsequent ctions. A separate section is dedicated to the le of chance and our incorporation of stochastic d deterministic approaches into the conceptual del.

ose propagules (seeds, buds, rootstocks, and ers) that survive disturbance on-site or are sseminated from off-site sources give rise to the tial flora. The initial flora includes those ecies available for colonizing the site following sturbance. The likelihood that the initial flora ludes a particular species depends on ironmental conditions (e), existing vegetation , and chance (c). Through the process of ecesis ements 1916), some of the initial flora ablish and grow to form the vegetation in the st year after disturbance(s). Individuals may ablish whenever suitable conditions for ecesis ur in the years following disturbance; however, ablishment is limited to the first year lowing clearcutting and fall broadcast burning the *Thuja plicata/Clintonia uniflora* habitat e. The process of ecesis is strongly influenced burn severity (b), life history characteristics individual species (l), and chance (c). Change vegetation from the first year (S_1) to sequent years (S_N) is the result of growth and biotic interactions that affect growth. Growth biotic interactions are affected by chance (c) and the life history characteristics of the successional species (l).

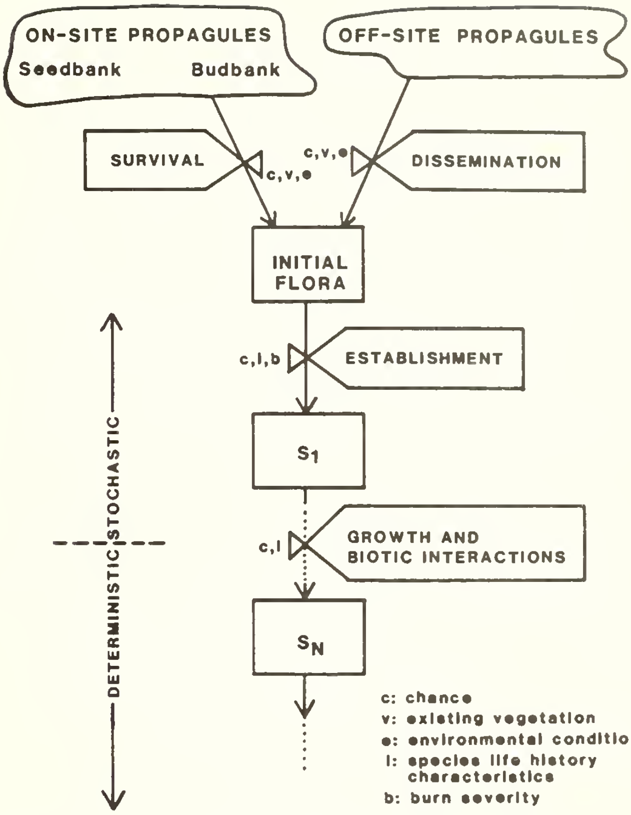

Figure 1.--Conceptual model of shrub succession following clearcutting and broadcast burning. The initial flora includes those species available for postburn colonization. It consists of those propagules surviving the burn on-site and those disseminated from nearby off-site areas. Species composition of the initial flora depends on chance (c), the vegetation existing before disturbance (v), and environmental conditions (e). Some of the initial flora establish to form the first year shrub community (S_1). The establishment process is affected by chance (c), life history characteristics of individual species (l), and burn severity (b). After establishment, changes in shrub communities to those of subsequent years S_N are the result of growth and biotic interactions. These processes are strongly influenced by chance and the life history characteristics of individual species.

The major postburn successional influences identified in the conceptual model are environmental conditions (e), existing vegetation (v), burn severity (b), life history characteristics of species (l), and chance (c). Environmental effects include physical site conditions such as soil conditions, elevation, slope, aspect, and forest habitat type. Tree canopy closure and seed bank and live shrub species composition of the forest vegetation existing before clearcutting may strongly influence successional development. Life history characteristics of species that affect disturbance response include possible reproductive modes, intrinsic growth rates, longevity, and shade tolerance. Burn severity affects the potential contribution of various reproductive modes to postburn regeneration, establishment and growth of species. Chance plays an important role in all early successional processes.

We incorporate the effect of chance on succession through stochastic modeling in addition to deterministic approaches. Shrub community dynamics in the first few postburn years are modeled stochastically. These include the processes of determination of the initial flora, establishment, early growth, and biotic interactions. Subsequent changes in shrub communities are represented deterministically.

On-site Propagule Sources

Understory vegetation is usually top killed by fire; therefore, most understory vegetation is adapted to regenerate after fire. Sources of regeneration are of two general types: on- and off-site (Lyon and Stickney 1976), which have also been called residuals and migrants (Clements 1916; MacMahon 1980, 1981). On-site sources may be dormant buds on surviving plants parts (the "bud bank") or dormant seeds stored on site in duff and surface soil (the "seed bank") (Roberts 1981).

The above ground parts of understory plants are usually partially or totally consumed and the cambial tissue killed or damaged by fire; however, the root system and subsurface plant parts may survive even intense fires. Understory vegetation commonly resprouts from previously dormant buds on rhizomes, root crowns, bulbs, corms, and other plant parts (Gill 1981; Heinselman 1981). Postburn sprouting is widespread in ecosystems worldwide (Keeley 1981). Postburn shrub growth from sprouts is often abundant and vigorous, particularly for low shrubs such as *Rosa, Symphoricarpos,* and *Spiraea* (Lyon and Stickney 1976). Root crown sprouting has been called the most important fire survival adaptation for northern Rocky Mountain shrub species (Lyon and Stickney 1976). It is particularly important for tall shrubs such as *Acer, Salix, Alnus,* and others (Lyon and Stickney 1976). Severe or deep burns, those that consume organic layers and heat the soil surface for some time, result in reduced sprouting response (Flinn and Wien 1977; Ohmann and Grigal 1979; Rowe 1983). This is likely due to direct lethal heating of the plant tissues but may also be due to changes in the postburn microenvironment such as soil water and temperature regimes or nutrient availability (Heinselman 1981). Generally, on-site seedling or sprout regeneration occurs even on severe burns (Heinselman 1981).

Seed banks may contribute significantly to postburn regeneration (Archibold 1979; Roberts 1981; and others). Seeds may lie dormant on site for many years, often through an entire successional cycle For instance, many *Ceanothus* species apparently produce abundant seed beginning shortly after establishment. These accumulate in the soil unti dormancy is broken, often by heat from fire (Gratkowski 1973). Postburn seedling regeneratio from seed bank sources may be very abundant. We found that eight of 12 common and abundant shrub species on the *Thuja plicata/Clintonia uniflora* habitat type relied on seed banks for postburn regeneration (Morgan and Neuenschwander, in preparation). Live fruiting shrubs of these most shade-intolerant early successional species were not present in the undisturbed forests, nor is off-site dispersal likely (Morgan and Neuenschwander, in preparation). Thus, the majority of seeds in the duff and soil seed bank must have been produced on-site in a previous shr stage.

Some seeds are specifically adapted to lie dorman until stimulated to germinate by heat from fire o the changed postfire environment. Germination of *Ceanothus* species is stimulated by heat scarification (Gratkowski 1973). *Ribes* (Quick 1956) and other species appear similar in their germination response to fire. Seeds of other species that lack specific adaptations for heat tolerance may survive fire by chance. The seedbe created by fire is seldom uniform. Even severe fires often leave small islands of unburned or on partially consumed duff. Seedling composition on such microsites is often different from that on more severely burned microsites. Regeneration fr seed banks may be enhanced by moderately severe fires (Heinselman 1981).

The on- and off-site propagules sources that predominate on a given site affect successional dynamics. On-site sources are immediately available and postburn response may be rapid as i the case when sprouting is abundant and vigorous. Off-site sources may be but are most often not as quickly available and abundant postburn.

Off-site Propagule Sources

Propagules may be disseminated from areas adjacen to burns by wind, animal, bird, or water vectors. Usually the propagules are small airborne seeds o fruits (Lyon and Stickney 1976). The importance off-site sources to a particular species varies with availability of suitable vectors and proximi of flowering source plants in unburned areas with or at the edge of burns. These factors are highl subject to topography and chance. Therefore, the postburn abundance of vegetation with off-site origins may be highly unpredictable (Lyon and Stickney 1976).

Species vary greatly in their adaptations to dispersal. Occasionally, off-site sources enable species to be very abundant postburn, as is often true with *Epilobium* species. Generally, however, off-site sources lead to infrequent and continuou establishment through time (Lyon and Stickney 1976). Shrubs that have seed adapted for wind spersal (such as *Salix, Acer, Betula,* and *Alnus* ecies) also rely heavily on sprouting for stburn regeneration.

itial Flora

e on- and off-site propagule sources determine e initial flora, those species available for stburn establishment (Lyon and Stickney 1976). e composition of the initial flora is strongly fluenced by environment, existing vegetation, and ance. The environmental conditions of the site fluence successional pathways (Zamora 1982) by miting the species potentially present on-site d in adjacent areas that might provide off-site urces of propagules. On-site sources are rticularly affected by the vegetation existing fore disturbance. Sprouting potential is a nction of age and vitality of shrubs (Naveh 1975; ll 1981). Thus, post-burn sprouting depends on e presence of vigorous shrubs in the undisturbed derstory. Many of the species important in early ral shrub communities are shade intolerant and able to exist under the closed canopy of the disturbed forest. Such species will sprout if ey are present in the stand before disturbance, t many rely on dormant seed stored on-site in ff and soil seedbanks. Stand history may affect edbank composition. On-site propagule sources ll be nonexistent if the time since on-site seed oduction exceeds seed longevity.

Many shrub species regenerate from more than one propagule source on a given site. *Salix scouleriana* may establish post-burn from root crown sprouts or from wind-blown seed (Lyon and Stickney 1976). *Rubus parviflorus* may sprout from rhizomes and regenerate from seed stored on-site in the seedbank. Establishment probabilities and early growth rates of seedlings and sprouts of the same species often differ greatly, hence it is useful to treat the reproductive modes of the same species as separate entities in the model until they become difficult to differentiate in the field. Seedlings and sprouts of the same species are probably sufficiently similar to be treated as equivalents in the model after the first few post-burn growing seasons.

Establishment

The species present in the first post-burn growing season will depend on the initial flora, but not all initial flora will survive and regenerate after fire. It is unlikely that establishment success will be proportionate to the abundance of propagules in the initial flora.

Successful establishment depends on the kind and severity of disturbance, mode of reproduction, and other factors, including weather, microsite conditions, and herbivory. Burn severity affects the overall postburn abundance of shrub seedlings and sprouts. Both rhizomatous and root crown sprouts are more abundant on low-severity than on high-severity burns. Burn severity reflects the potential damage to seeds and plant organs in the duff and soil (Flinn and Wien 1977). It also strongly affects the postburn microenvironment. Thus, burn severity may strongly influence the likelihood of establishment from both seed and sprout propagules.

In the simplest case, establishment is limited to immediately following fire. Virtually all important early successional species establish in the first postburn year (Lyon and Stickney 1976; Gomez-Pompa and Vazquez-Yanes 1981; Zamora 1982). No significant additional establishment of either shrub seedlings or sprouts occurred after the first growing season on the fall broadcast burns we observed. Immediate establishment of shrubs is similarly probable for productive sites where establishment is primarily from on-site sources. Factors affecting regeneration are particularly important influences on successional pattern when establishment is immediate and characteristics of the species that do establish may strongly affect the pattern of successional development for many years. For instance, the apparent forb, shrub, and tree "stages" of succession are the result, not of successive establishment and replacement, but of differential growth rates of species that establish simultaneously (Lyon and Stickney 1976).

Growth and Biotic Interactions

Shrub community dynamics subsequent to establishment are the result of survival and differential growth of individuals (Lyon and Stickney 1976). It is useful to treat growth and establishment as separate processes even if they occur simultaneously, which accommodates the site poor for establishment but favorable to growth (Stage and Ferguson 1982).

In our conceptual model, growth is expressed as net growth, including mortality. Biotic interactions include competition, interference, and any other influences of one organism upon another that contribute to differential growth and size potential. Growth and biotic interactions encompass all processes, including the innate characteristics of individual shrub species, which determine apparent dominance over time (Lyon and Stickney 1976).

The mechanisms of growth and biotic interactions are difficult to quantify. Growth is a function of intrinsic growth rate, competition, mode of reproduction, physical site characteristics, weather, time, and other factors. Chance plays a major role, contributing to the spatial and temporal variability of these effects. Early growth is especially subject to a variety of factors. A few of these can be identified and quantified. Others may best be treated as chance influences. In a model, this is accomplished through use of stochastic functions. Growth and biotic interactions may be adequately represented by simple stochastic equations as in JABOWA (Botkin and others 1972) and the many models derived from it (Shugart and others 1981).

Role of Chance

Chance plays an important role in succession (Franklin 1982). It affects every successional process, whether that effect is identified and quantified in the model or not. The role of chance can be represented in simulation models by random and probabilistic components. Models that incorporate such effects are stochastic. Predictions of stochastic models are not single, absolute numbers; instead, they consist of a range of numbers with associated probabilities that express the likelihood that a particular outcome will occur. Inclusion of a separate stochastic element in a model stresses the important influence of chance on successional pattern (Franklin 1982). Models are simplifications. The effort to build an accurate model forces an elucidation of the most critical processes and controlling influences of succession. Many less important effects must be excluded. Stochastic elements may be used in simulation models to represent the influence of some of these excluded effects. Thus, stochastic functions may be used in simulation models to represent both natural variation due to chance and variability due to other influences on successional processes than those included in the model.

Deterministic models are usually simpler and less expensive to execute than stochastic models. Stochastic predictions more realistically represent natural variability in postburn succession.

We believe that a combination of stochastic and deterministic approaches provides flexibility and accuracy in a less expensive model. Stochastic functions can be used to represent processes that are strongly influenced by chance and by many factors that are difficult to identify and quantify, namely determination of initial flora, establishment, early growth, and biotic interactions. Shrub community dynamics following establishment and early growth are less subject to the vagaries of chance. A deterministic model may adequately represent successional development after the first few postburn years.

LIMITATIONS

The conceptual model presented here and the examples used to demonstrate it draw heavily on our experience with postburn shrub succession in northern Idaho. We hope that this model is generally applicable to postburn succession; however, differences in detail are likely. For instance, seed banks are probably not as significant as contributors to postburn regeneration of understory vegetation in some other habitat types. Johnson (1975) found evidence for lesser importance of seed banks in northern ecosystems. Relative contribution of on- and off-site sources may also be strongly influenced by fire regimes (Keeley 1981). Establishment may extend through many years elsewhere, especially if off-site sources predominate. This could strongly affect successional dynamics. In such situations, the relative importance of the successional processes and influences may differ from the one described.

Much data may be required to obtain the knowledge of the on- and off-site propagule sources needed apply this model. This is a serious limitation unless indicators of disturbance response can be easily identified. Seed morphology may be indicative of the likelihood of long-lived dorman in seedbanks, the potential importance of seedban may be predictable by habitat type, and rooting habit may offer clues to sprouting potential. Ideally, adaptive characteristics of species coul be simply identifed from such general morphologic and ecological characteristics.

The conceptual approach is untested. Pilot simulation model development suggests that the modeling approach has promise. Once complete, th simulation model will be tested against field observations of shrub succession on the *Thuja plicata/Clintonia uniflora* habitat type. Results should reflect whether the conceptual approach is appropriate.

CONCLUSIONS

The complexity of early seral succession can be unraveled when casual factors are identified. We have outlined a conceptual model of shrub succession following clearcutting and broadcast burning. The model incorporates the critical influences and processes determining successional development. Environmental conditions, existing vegetation, life history characteristics of speci available for colonization, kind and severity of disturbance, and chance are identified as importa influences on successional patterns. The critica successional processes are determination of the initial flora, establishment, growth, and biotic interactions. Many of these influences and processes have been previously identified as important determinants of successional patterns. Here they are synthesized into a simple conceptua model of shrub succession following fire.

Development of our conceptual model draws heavily on the conceptual models presented by MacMahon (1980, 1981) and Lyon and Stickney (1976), existi literature, and previous successional modeling approaches. The best attributes of many separate approaches are combined in the conceptual model. The resulting integration differs substantially from any of the parts. We recognize the role of chance in successional development. Chance is mo influential in the first few postburn years, and represent early successional processes stochastically. Deterministic equations are adequate representations of community dynamics subsequent to establishment and early growth, whe changes in the community are less subject to the vagaries of chance. This time-dependent linkage stochastic and deterministic equations in a singl successional model is unique. The conceptual mod provides a valuable synthesis of ideas valuable i developing an understanding of the course of earl seral shrub succession following clearcutting and burning.

orest successional models have been used to ntegrate existing knowledge, explore theories, est specific hypotheses, and stimulate critical hinking about the causes and consequences of uccessional dynamics (Shugart and West 1980; ranklin 1982). We hope that the conceptual model resented here will stimulate similar critical hinking about succession of forest understory pecies.

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INFLUENCE OF FIRE SEVERITY ON RESPONSE OF EVERGREEN CEANOTHUS

Nonan V. Noste

BSTRACT: Fire plays an important role in *Ceanothus* *elutinus* habitat. Its impact varies with season nd severity of fire. Knowledge of the interaction etween fire severity and evergreen ceanothus abitat can assist managers in estimating the ffect of fire on evergreen ceanothus and in eveloping burning prescriptions.

NTRODUCTION

eanothus velutinus (Dougl.), evergreen or snowbrush eanothus, is an important wildlife browse species hat provides a critical winter food resource for eer and elk (Klebenow 1962; Martinka 1976). Ever-reen ceanothus is a component of seral shrub ields, as well as of open xeric or developing early eral conifer stands. Evergreen ceanothus is also f special interest to managers because it fixes itrogen (Zavitkovski and Newton 1968; Jurgensen nd others 1979) and competes with tree seedlings ratkowski and Lauterback 1974). Fire plays a rominent, if not critical, role in establishing nd maintaining these shrub fields and forest tands. Fire can be used in managing stands with a *eanothus* component (Hall 1977).

he following discussion of the response of ever-reen ceanothus to fire emphasizes the effect ot ire treatment severity. This paper summarizes nformation on the biology of evergreen ceanothus nd emphasizes management strategies for using fire o encourage or discourage reproduction and growth.

PECIES CHARACTERISTICS

vergreen ceanothus commonly grows in dense clumps r patches but ranges from scattered individual ants to nearly complete site domination. There e two varieties of *Ceanothus velutinus*. *Ceanothus* *lutinus* var. *laevigatus* (Hook.) Torr. and Gray distinguished by smooth (glabrous) leaves, at ast on the veins on the underside of the leaves. s range is the west Cascade Mountains from itish Columbia to northern California. *Ceanothus* *lutinus* var. *velutinus* has pubescent leaves vered with short fine hairs. It is found east of e Cascade Mountains from British Columbia to California and Nevada and east to South Dakota and Colorado (Hitchcock and Cronquist 1961). Evergreen ceanothus is known under several aliases, including shinyleaf, varnish leaf, buckbrush, wild-lilac, stickylaurel, grease wood, and tobacco-brush. The seasonal growth patterns of evergreen ceanothus in the Rocky Mountains can be inferred from published phenological information (Schmidt and Lotan 1980; Schopmeyer 1974). The western variety (*laevigatus*) is sometimes treelike and reaches a maximum height of 20 ft (6 m) (Little 1979). The eastern variety (*velutinus*) is approximately 2 to 6 ft tall (0.5 to 2 m), occasionally up to 13 ft (4 m) Hitchcock and others 1961).

In Montana, Morris and others (1962) associate evergreen ceanothus with Douglas-fir and spruce-fir zones. In north central Washington, evergreen ceanothus is responsible for much of the difference in shrub cover in the ponderosa pine and Douglas-fir forests (Tiedemann and Klock 1976). Average cover 4 years after burning was 12.7 percent on south slopes compared to 6 percent on the west aspects.

Explosive flammability in these stands is attributed to retention of dead leaves on sclerophyllous (thick hard leaves) understory vegetation such as evergreen ceanothus. Fuel from winter dieback of evergreen ceanothus could increase flammability. Stickney (1965) attributed dieback during the winter of 1962-63 in the Missoula, Mont., area to a severe drop in temperature followed by a mild period.

Some of the species that dominate early successional phases often have dormant, ground-stored, fire-activated seeds. This is true of evergreen ceanothus, whose seeds are characteristically small (61,400 to 152,000/lb) (Schopmeyer 1974), rounded to spherical, smooth texture, and without obvious means of dispersal much beyond the limits of the parent plant (Lyon and Stickney 1976). Evergreen ceanothus seeds are long-lived, viable on forest sites for 200 to 300 years (Gratkowski 1962), and require heat treatment to germinate (Dyrness 1973). Pressure of the two edges of the hilar fissure against each other is sufficient to prevent moisture penetration into the seed. Heat induces germination by opening the hilar fissure sufficiently to permit passage of water into the seed (Gratowski 1962). The species can resprout from the root crown after being burned and is intolerant to shade.

Lyon and Stickney's (1976) model for predicting a plant species' success links fire survival strategy to its abundance in early seral communities. Evergreen ceanothus fits two fire survival categories.

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When the on-site survival mechanism (meristematic tissue) is sprouting from burned root crowns, their model predicts a minor decrease in response to severe wildfire. If the survival mechanism is long viability on-site seed, a large increase after these severe wildfires is expected.

FIRE SEVERITY

The concept of fire severity combines the effect of the heat pulse up to the above-ground vegetation and down into the soil (Ryan and Noste in press). The heat pulse down has been termed ground char and is evaluated by classifying postburn soil and fuel characteristics. When used in relation to *Ceanothus velutinus* reproduction and regeneration, the term "fire severity" inplies that the heat pulse is down to the soil. It is difficult to separate fire intensity and the upward heat pulse from ground char in evaluating measures to characterize fire in relation to fire effects. In the literature, ceanothus response has been related to several fire measures such as intensity and percen duff reduction. This information will be interpreted in accordance with the concept of fire severity.

Critical soil temperature inducing germination range from 113° to 149° F (45° to 65° C) (Gratowsk 1962). A minimum 8-minute exposure to dry heat induces germination, with further exposure having no additional influence. Mortality increases heat treatment information on the western variety (*laevigatus)*, and it is commonly inferred that it also applies to the variety *velutinus*. Solar insolation on unburned sites apparently also is often sufficient to stimulate germination (Dyrness 1973). The general relationship of *Ceanothus velutinus* to fire severity is illustrated in table 1.

Table 1.--Response of *Ceanothus velutinus* (CEVE) to fire severity[1]

Preburn condition	Response				
Extant plants (CEVE shrubs present)	Aerial crown	Kill	Shrub	Mortality	
	All shrubs resprout	Most shrubs resprout	Few shrubs killed	Many shrubs killed	
Dormant, viable seed (CEVE seed present in forest floor or ground)	Untreated	Fire treated			
	(below critical temperature)	(above critical min. temp.)			
		Nonlethal range		Lethal range	
	Seeds remain dormant	Uppermost seeds activated	Most activated	Few seeds killed	Many seeds killed
No seeds or extant plants present (CEVE absent from site in all forms)		NO RESPONSE			
	No resprouts or seedling evident in postfire community				
	Low	FIRE SEVERITY GRADIENT			HIG

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[1] Personal communication, Peter F. Stickney, Missoula, Mont.: U.S. Department of Agriculture, Forest Servic Intermountain Forest and Range Experiment Station, Forestry Sciences Laboratory, Feb. 1984.

RE SEVERITY RELATIONSHIP

eliminary results of a study by Arno and mmerman (1982) describe a relationship between re severity and establishment of evergreen anothus. On the Douglas-fir/ninebark (*Pseudotsuga nziesii/Physocarpus malvaceus*) habitat type fister and others 1977), a medium or hot wildfire broadcast burn on a site with evergreen anothus seed in the soil produces an evergreen anothus community type. In Douglas-fir/blue ckleberry (*Pseudotsuga menziesii/vaccinium obulare*) types, a severe burn produces an ever- een ceanothus community type.

a forest succession study, Stickney (1980) ovides data on plant response in relation to fire verity for the larch/Douglas-fir forests of stern Montana. There was no evergreen ceanothus the plots before treatment. The subalpine fir/ eencup beadlily (*Abies lasiocarpa/Clintonia iflora*) habitat type was treated at the Miller eek prescribed fire study area on the Flathead tional Forest. Evergreen ceanothus became tablished at low levels (5 and 7 percent cover in years) on two south exposure plots burned by ldfire (table 2). This wildfire could be judged vere based on Stickney's observation that no duff yer remained (DeByle 1981).

The western redcedar/queencup beadlily (*Thuja plicata/Clintonia uniflora*) grand fir/queencup beadlily (*Abies grandis/Clintonia uniflora*), and Douglas-fir/blue huckleberry habitat types were sampled at the Newman Ridge prescribed fire study area on the Lolo National Forest (Stickney 1980). The cold, north-slope western redcedar/queencup beadlily site had no ceanothus response (see unit N2 in table 2).

The four plots in the grand fir/queencup beadlily habitat type had varied response, with no evergreen ceanothus on a west exposure plot (W2) burned by a relatively severe fire. Lack of seed source may explain the absence.

A west slope site on Newman Ridge burned (W3) by a low-severity fire had a relatively high evergreen ceanothus cover (24 percent in 6 years). When treated with fires of similar severity, evergreen ceanothus cover was 22 percent after 6 years on a south slope (S2) compared to 11 percent on an east slope. A Douglas-fir/blue huckleberry plot on a south slope treated with a severe fire had 41 percent cover in 6 years, which must approach the maximum potential for evergreen ceanothus establishment and growth.

ble 2.--Fire effects on Miller Creek-Newman Ridge sites in western Montana (Stickney 1980)

cation, it no.	Habitat[1] type	Fire intensity (water loss)	Postburn duff depth	Duff reduction	Evergreen ceanothus Preburn	Evergreen ceanothus 6-year postburn
		gm	cm	Percent	Percent	Percent
Miller Creek						
N6	Subalpine fir	303	7.0	14	0	0
N7	Subalpine fir	242	4.5	49	0	0
N8	Subalpine fir	266	6.0	6	0	0
E6	Subalpine fir	243	2.7	49	0	0
E8	Subalpine fir	881	6.6	31	0	0
E9	Subalpine fir	834	4.7	38	0	0
S1	Subalpine fir	286	4.3	16	0	0
S2	Subalpine fir	--	--	--	--	--
W3	Subalpine fir	423	4.5	11	0	0
W10	Subalpine fir	519	2.4	52	0	0
W15	Subalpine fir	228	6.4	11	0	0
N man Ridge						
E3	Grand fir	820	2.0	35	0	11
N2	Western redcedar	1,297	2.7	51	0	0
S2	Grand fir	813	1.9	47	0	22
W2	Grand fir	1,253	2.2	59	0	0
W3	Grand fir	283	1.0	63	0	24
S3	Douglas-fir	1,976	.3	94	0	41
W dfire in standing timber						
S12	Subalpine fir	--	--	--	--	7
S13	Subalpine fir	--	--	--	--	5
W6	Subalpine fir	--	--	--	--	0

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[1] All units were in the *Clintonia uniflora* phase of the habitat type except unit S3, which is in the *Vaccinium globulare* phase.

Percent duff reduction is an index of depth-of-char, so the concept of fire severity can be applied to the data in table 2. There is a direct trend between percent duff reduction and ceanothus cover. The wildfires and prescribed fires with ceanothus response were severe.

SPRING AND FALL BURNS

The effect of spring and fall prescribed burning is being studied on a seral shrub field in a Douglas-fir/ninebark (*Pseudotsuga menziesii/physocarpus malvaceous*) habitat on O'Keefe Creek near Missoula, Mont. The area is a critical big game winter range, and evergreen ceanothus is an important browse species on the site. The idea that more severe fall prescribed fires provide an alternative to traditional spring fires to rejuvenate seral shrub fields is being evaluated. Fall fires are generally more severe because the larger fuels are drier and soil moisture lower.

Plots of 50 and 125 acres (20 and 50 ha) were burned on October 3, 1979, and April 16, 1980, respectively. The fall of 1979 was dry, and the fire was intense considering the limited fuels on the site. Flame lengths on the fall fire averaged 9 ft (3 m) and contrasted to 3 ft (1 m) flame lengths on the spring burn. A detailed description of fuel loadings, fuel moisture, weather conditions, and fire behavior, which were needed to develop a burning prescription, has been published along with vegetation sampling methods (Noste 1982).

Twenty individual evergreen ceanothus plants were observed before the burns and 1 year after (1980). Twelve of 20 marked plants were killed on the more intense fall burn; there was no mortality on the spring burn. Thus, first growing season survival rates of mature plants were 40 percent on the fall burn and 100 percent on the spring burn.

Evergreen ceanothus seedlings were not counted the first growing season after the fall burn (1980), but many were present. Wildlife grazing during the relatively open (free from snow) 1980-81 winter severely reduced the number of ceanothus seedlings. In 1981, evergreen ceanothus seedlings occurred on 38 percent of the plots (0.5 by 0.5 m) on the fall burn, and the seedlings count indicated a density of 18,000 seedlings per acre (45,000/ha). Seedlings have not been seen on the spring burn. A sample of 50 plots (0.5 by 0.5 m) in both the spring and fall burn during the fourth growing season (1983) indicates 6,500 seedlings per acre (16,000/ha) surviving on the fall burn and none on the spring burn.

The differential response of evergreen ceanothus to fall and spring burning is shown in measurements of percent cover in the following tabulation:

Treatment year	Percent cover
Spring	
preburn	11.5
1980	12.7
1981	19.6
1982	21.5
Fall	
preburn	18.5
1980	0.2
1981	6.7
1982	10.4

During the first growing season following the spring burn, treatment cover (12.7 percent) exceeded the preburn value (11.5 percent). Cover has nearly doubled (21.5 percent) during the third growing season. All of these plants resprouted from root stocks. The fall burn set evergreen ceanothus cover back to 0.2 percent the first year and in the third growing season had expanded to about half of preburn coverage (18.5 and 10.4 percent). This cover nearly all originated from plants that resprouted; small seedlings accounted for very little.

DISCUSSION

Knowledge of the relationship between fire severit and evergreen ceanothus can facilitate development of burning prescriptions. Severe fires are generally needed to establish evergreen ceanothus seedlings. Some interactions between fire severity, aspect, and habitat type are also significant. More severe fires are needed in cool moist habitat types than in warm habitat types. The greatest potential for establishing evergreen ceanothus is on south slopes, followed in order by west and eas slopes. The Douglas-fir habitat types have more potential for ceanothus than grand fir habitat types. Subalpine fir habitat types have more potential for evergreen ceanothus than western redcedar habitat types on north slopes or northeas slopes.

Success in regeneration and rejuvenation of evergreen ceanothus following burning is extremely variable, presumably due to variation in duff moisture and fire severity (Wright and others 1979). Late summer or fall burns, however, do increase the number of seedlings and resprouts (Wright and others 1979). The O'Keefe Creek results support this claim. The more intense fall fire produced seedlings at O'Keefe Creek, whereas the spring fire increased evergreen ceanothus cove in the short run.

Martin (1982) has described an effort to reduce evergreen ceanothus in central Oregon ponderosa pine (*Pinus ponderosa*). A burning treatment is designed to exploit stress on the plant and increase the probability of mortality. The treatment combines a preharvest underburn to weaken mature plants and germinate some seed, with a subsequent postharvest burn. This concept of frequen ess intense fires is being evaluated. Successive ires at relatively short intervals have been shown o retard shrub growth (Isaac 1940; Gratowski 1962).

he information presented here, although not in the orm of a predictive model, can be used as a guide or estimating the effect of fire on evergreen eanothus. The manager wanting to increase or ecrease the evergreen ceanothus component of a eral shrub field or a forest stand can be more pecific in setting objectives and evaluating esults and through this process can learn to maniplate this species through the use of fire. Weather onditions and fuel availability may limit attaining he severity of treatment required to accomplish urning objectives.

ow-severity spring burns can increase ceanothus over immediately and relatively inexpensively hrough regrowth from root crowns. Severe summer nd fall burns stimulate germination of groundtored seed to produce young plants, thus providing long-term increase. Multiple low-severity fires rovide an approach for reducing the ceanothus omponent. Objectives should reflect realistic ttainable increases in cover or number of seedings and should only reduce ceanothus cover enough allow tree seedlings to compete.

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A compilation of 11 papers in which authorities discuss the impacts of fire on wildlife habitat and wildlife populations. Presentations cover bobwhite quail, nongame birds, white-tailed deer, bighorn and Stone's sheep; and the response to burning of curlleaf cercocarpus, aspen, evergreen ceanothus, and antelope bitterbrush.

KEYWORDS: wildland fire, fire management, wildlife habitat, prescribed burning, wildlife management, fire ecology, postfire succession, wildland management, fire effects

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October 1985

Coniferous Forest Habitat Types of Central and Southern Utah

Andrew P. Youngblood
Ronald L. Mauk

CLEMSON UNIVERSITY
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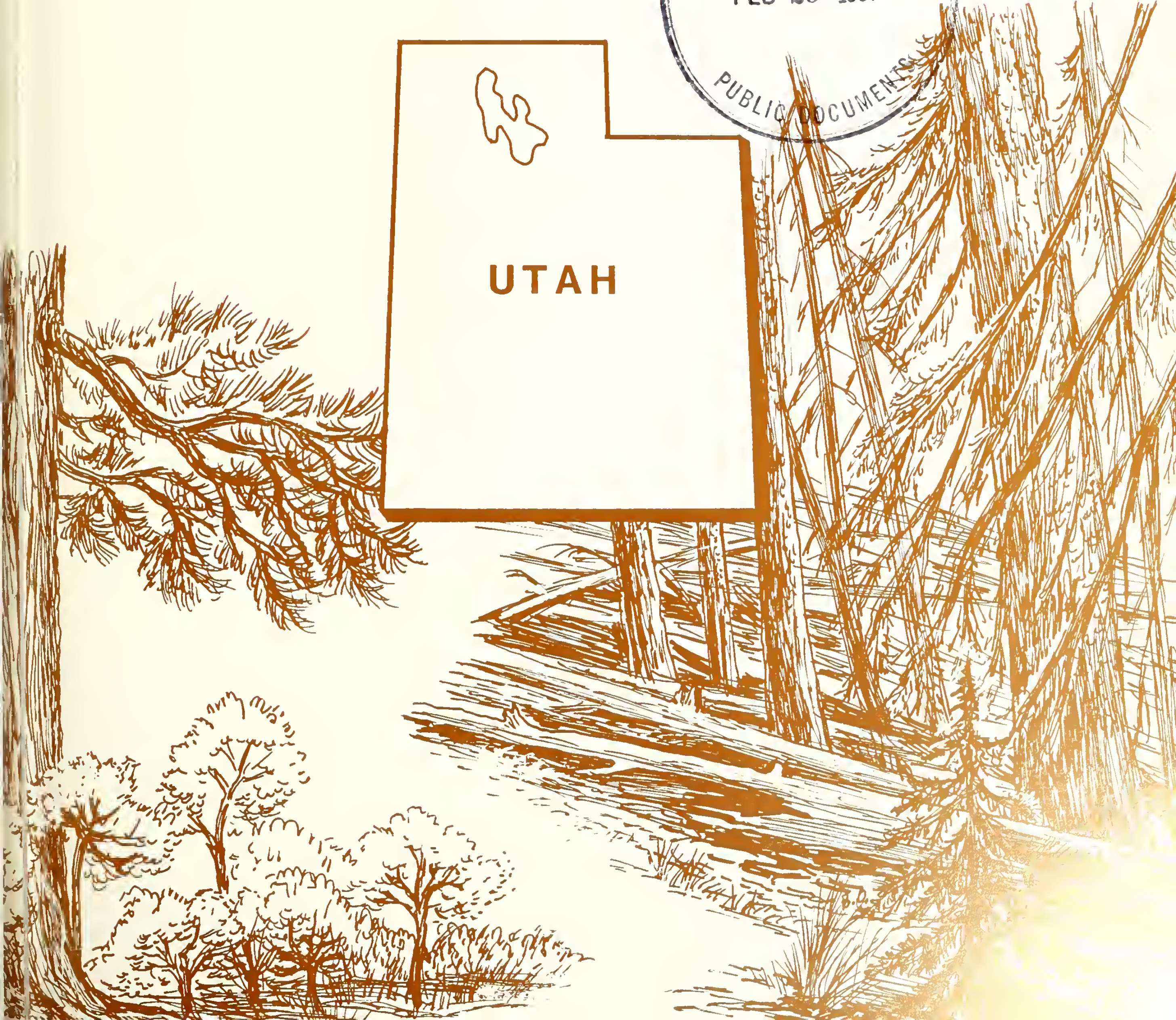

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RESEARCH SUMMARY

A habitat type classification for the coniferous forests of central and southern Utah includes the hierarchical taxonomic system of land classification that is based on potential natural vegetation of forest sites and uses data from more than 720 sample stands. A total of 37 habitat types within seven series are defined and described. A diagnostic key will help in field identification of the habitat types based upon indicator plant species.

In addition, descriptions of mature forest communities include information on the ecological distribution of all species. Potential productivity for timber, climatic characteristics, surface soil characteristics, and distribution maps are provided for the major types. Preliminary silvicultural and wildlife habitat implications for natural resource management are based on field observations and current information.

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Coniferous Forest Habitat Types of Central and Southern Utah

Andrew P. Youngblood
Ronald L. Mauk

NTRODUCTION

The forests of central and southern Utah occupy an
ea of complex geology and terrain, contrasting climatic
tterns, and merging floristic regimes. The resulting
versity of forest vegetation is often in various stages
successional development because of past disturbance.
ach unit of vegetation may have a host of inherent
source values such as forage production for livestock,
ldlife habitat for big game, or timber for commercial
oduction. These values change as the vegetation
anges. Classification of the forests for specific, single-
source purposes have often proved inadequate when
plied to different resources. Resource managers fre-
ently must rely upon a classification system that is
t structured for one purpose but rather serves a broad
ectrum of management needs simultaneously.

Classification of forested lands by habitat type pro-
des an integrated, ecosystem-management approach to
source categorization. Units within the classification
e sites or areas of land. The first habitat type system
site classification was developed by Daubenmire
952) for northern Idaho and eastern Washington. Later
rk by Daubenmire and Daubenmire (1968) refined the
ncept and served as the model for most subsequent
assifications. Classifications have now been developed
r many areas in the Western United States (Pfister
76). These provide the resource manager with a com-
on framework for communication, management, and
search.

Within central and southern Utah, Pfister (1972) has
ssified lands potentially capable of supporting *Abies*
siocarpa and *Picea engelmannii*. Extensive areas at
ver elevations supporting montane forests remained
studied. In 1975, the Intermountain Region and the
termountain Forest and Range Experiment Station of
e Forest Service, U.S. Department of Agriculture,
tered into a cooperative research effort with the
partment of Forestry and Outdoor Recreation at Utah
ate University to complete a State-wide habitat type
ssification of conifer-dominated lands. Much of the
rly effort was directed toward completion of a classifi-
tion for northern Utah, including the Wasatch and
nta Mountains. Results of this work are presented by
auk and Henderson (1984). Beginning in 1975, field
ews led by Charles Kerr conducted sampling on the
rthern end of the Wasatch Plateau near Price, UT. As
rt of a broad wildland classification and information
rieval system, their work has been reported by Kerr
and Henderson (1979). Concurrently, additional field crews led by Steve Simon sampled a larger portion of the same general area in an attempt to describe existing plant community types. From 1979 to 1981, an effort led by Ronald Mauk resulted in completion of field sampling throughout central and southern Utah. Data from (1) Pfister's (1972) thesis, (2) Kerr and Henderson's (1979) work near Price, (3) Simon's work on the Wasatch Plateau, and (4) fieldwork from 1979 to 1981 were combined for analysis and classification of habitat types. The resulting compilation forms the basis of this report.

The area covered by this classification extends roughly from Soldier Summit and Thistle on U.S. Highway 6 in central Utah south to the Arizona border (fig. 1). Specifically, the area includes lands within three National Forests (Manti-LaSal, Fishlake, and Dixie) and forested parts of Bryce Canyon National Park and Cedar Breaks National Monument. A small section of the Ashley National Forest south of Duschesne is included because it was not considered within the northern Utah classification. We have also included forested lands immediately adjacent to the above-named areas, regardless of ownership.

The objectives of this study were:

1. To contribute to a broad regional classification program of the Forest Service by the development of a habitat type classification for conifer-dominated forest lands of central and southern Utah based upon the potential climax vegetation.
2. To describe the general geographic, topographic, climatic, and edaphic features of each habitat type.
3. To describe the structural and floristic characteristics of late seral or climax vegetation of each habitat type.
4. To present information on successional development, resource values, and management opportunities for each habitat type.

This classification is intended to cover forested lands that are potentially capable of supporting at least 25 percent canopy cover of conifers, excluding the woodland species of *Juniperus osteosperma, Juniperus scopulorum, Pinus edulis*, or *Pinus monophylla*. Some lands supporting certain plant communities of questionable successional status were also not included. Riparian stands dominated by *Populus angustifolia* or *Populus fremontii* were ignored unless *Picea pungens* was also present. *Populus tremuloides* stands not having a well-developed understory of conifer are best described by a more specific classification resulting from the work of the

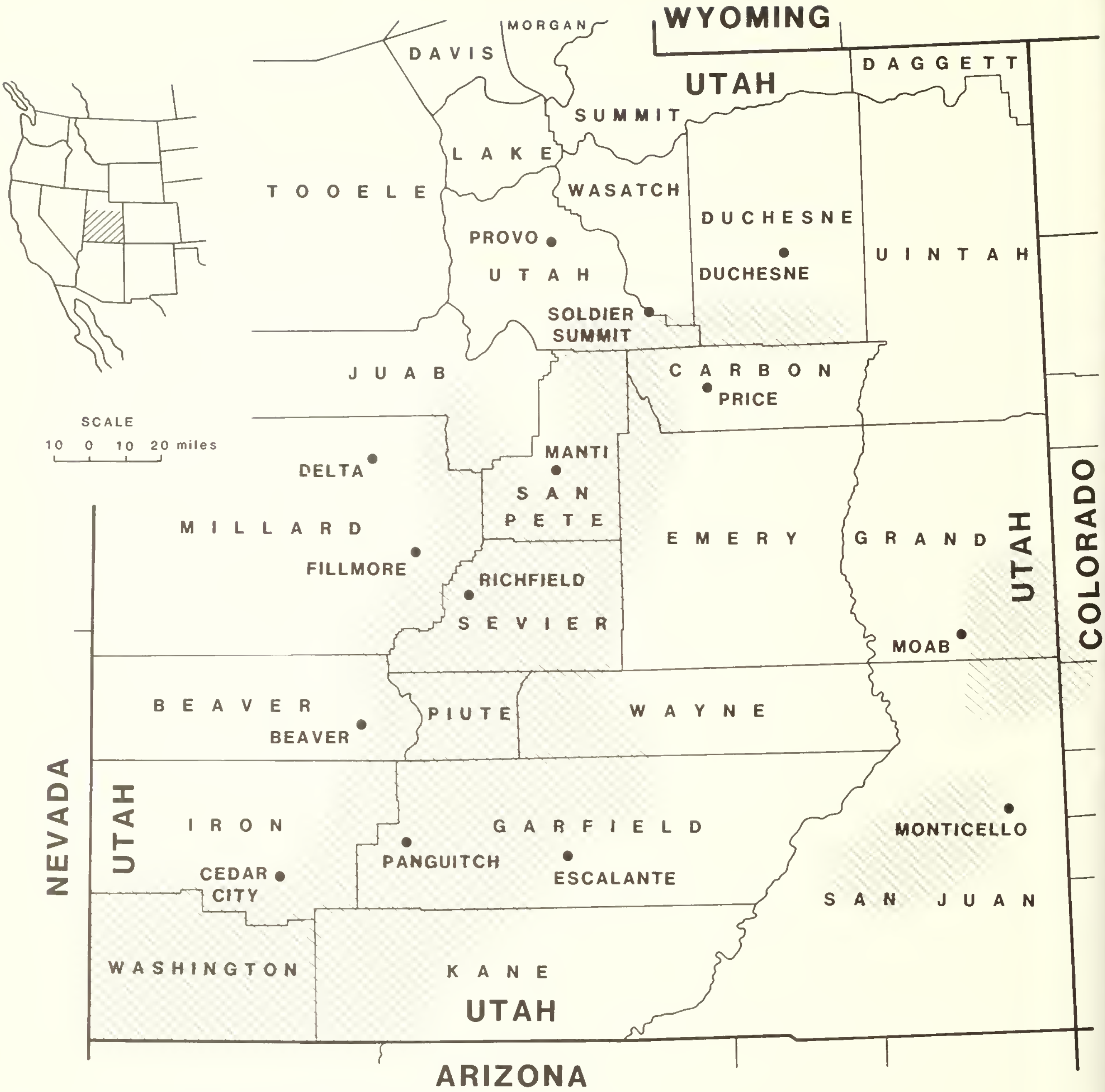


Figure 1.—Area covered by this classification (shaded) showing counties and major towns.

Intermountain Research Station (Mueggler and Campbell, in prep.). Likewise, shrublands dominated by *Quercus gambelii* or *Cercocarpus* were ignored unless the succession to conifers was obvious.

To provide a continuity with adjacent areas, this classification follows similar organization and terminology established by Pfister (1977) and used in other portions of the Intermountain Region (Steele and others 1981; Steele and others 1983; Mauk and Henderson 1984).

METHODS

Although fieldwork extended through 15 years and involved many individuals, overall concepts of sampling procedures and approaches remained relatively constant Our purpose was to develop a natural taxonomic classif cation of forest environments based upon the potential climax vegetation and the site it reflects.

ield Methods

The objective of field sampling was to collect data on full range of environmental conditions for the forested eas of central and southern Utah. The approach to ampling was similar to the "subjective without preconived bias" concept of Mueller-Dombois and Ellenberg 974), in that placement of plots was made without any ssumption of eventual classification or apparent pplicability to specific management problems, but ather for the representation of homogeneous vegetation. ield procedures generally follow those established by ranklin and others (1970), and modified by Henderson nd West (1977) and Steele and others (1981, 1983).

Elevational road and trail transects were selected to eflect the range of environmental conditions of the area. rief stops were made to note characteristics of potenal sample stands such as overstory, undergrowth, subrate, topographic features, and the relationship to djacent stands. Reconnaissance plots were then ubjectively located in the most representative and omogeneous parts of the most mature stands of the rea. Obvious ecotones, microsites, exceptionally dense umps or openings, or areas of recent severe disturbance ere avoided.

Reconnaissance plots of about one-eighth acre (500 m^2) ere circular, with the centers generally referenced to hysical road or trail landmarks to make return visits asier. For each plot, records were made of slope and spect to the nearest degree, slope position and configuation, elevation to the nearest contour (USGS 7½- or 5-minute topographic map), and general location.

Canopy coverage amounts of all undergrowth vascular lant species were ocularly estimated to the nearest perent from 1 to 10 percent and to the nearest 5 percent hereafter. Also noted was the presence of species in the tand but not in the plot, and species with trace mounts less than 1 percent. From 1968 to 1970, Pfister sed six coverage classes; during the analysis these data ere converted to the midpoint of the class. The practice f multiple small quadrats (Daubenmire 1959; Daubenmire nd Daubenmire 1968) was occasionally used for calibraion and coordination among samplers. All unidentified lants on each plot were collected for subsequent idenification or verification.

Canopy coverage estimates of tree species were made y three size classes: less than 1 dm diameter at breast eight (d.b.h.), 1 to 3 dm d.b.h., and greater than 3 dm .b.h. A stem tally by decimeter diameter classes was sed to calculate basal area and volume for all plots xcept those by Pfister during 1968 to 1970 and by imon during 1976. Trees less than 4.5 feet (1.37 m) tall ere counted in a circular subplot, centered in the reconaissance plot, with an area of 1,075 ft^2 (100 m^2). Several elatively free-growing trees of each species for each plot ere measured for height, age, and diameter to estimate rowth and site potential.

On most plots, thickness of the litter layer, texture of he upper 10 inches (25 cm) of soil, presence of charcoal, nd relative presence of coarse fragments were noted. over of exposed rock and bare soil was recorded. Bedock and surficial geology were determined using geologic maps (Stokes and Madsen 1961; Hintze 1963; Hintze and Stokes 1964).

Finally, notes were made on stand and fire history, past disturbances by insects, disease, wildlife, or livestock, and general relationships of the sampled stand to proximal vegetation types.

The data base for the development of the classification consisted of 727 plots, of which 110 were collected by Pfister from 1968 to 1970. From 1975 to 1976, Kerr sampled 76 stands along a narrow transect across the Wasatch Plateau. In 1976, an additional 78 stands of mature conifer were sampled by teams led by Simon. The remaining 463 plots were obtained from throughout the study area beginning in 1979. The distribution of sample stands is presented by geographical area in appendix A.

Office Methods

Analysis and compilation of a complete forest habitat type classification for the study area began in early 1983. The general procedures used are similar to work elsewhere in the Intermountain Region.

1. Sample data, collected by teams led by Mauk, were computer-coded. Stands were separated into groups having the same potential climax tree species. Synthesis tables (Mueller-Dombois and Ellenberg 1974), consisting of sample plot species and canopy coverage values, were computer-generated for each group. These tables were studied in detail to determine consistent differential distribution of species. Synthesis tables were rearranged several times in order to group similar stands into associations.
2. Characteristic vegetational and environmental factors for the plant associations were identified and briefly described. A first approximation of a dichotomus key, based upon diagnostic plant species, was developed.
3. Constancy and average cover values were calculated for the important species of each association. The key and preliminary habitat type factors were compared to published classifications for the surrounding areas to determine overlap and maintain continuity.
4. The preliminary key and classification were field-tested throughout the study area during the summer of 1983. This helped validate the groupings, clarify relationships with adjacent types, and derive potential management implications.
5. During the fall of 1983, the additional sample stand data were incorporated. Repeated synthesis tables with new groupings reflected a continual revision based upon the supplementary data and field testing.
6. Finally, a revised key was written and used to place all sample stands into their assigned type. This process required additional minor modifications to the key. Less than 4 percent of the sample stands did not fit the resulting classification. These apparently represent ecotones, vegetational mosaics, unusual seral conditions, or areas with unusual recent disturbance; it is possible that a few may reflect potential, localized habitat types for which we have insufficient data. Unclassified stands are briefly discussed following habitat type descriptions.

7. A description was prepared for each habitat type, including a map showing the known locations, a general discussion of the physiological environmental features and distribution, the key vegetation and successional trends, an overview of geologic and soil features, any preliminary management implications, and the relationship to similar conditions described elsewhere.

8. This classification can serve as a foundation for developing site-specific management implications such as wildlife habitat manipulation, fire effects studies, and silvicultural prescriptions. One of the key management implications developed in conjunction with this study is the appraisal of timber productivity for natural stands. A more detailed discussion of this is provided in the discussion section of individual attributes of habitat types following type descriptions.

Taxonomic Considerations

Unfortunately a complete, up-to-date flora for the study area was not available during the field sampling. Therefore, identifications were based on a number of treatments, including Harrington (1954), Hitchcock (1971), Cronquist and others (1972), and Hitchcock and Cronquist (1973). Nomenclature and synonomy were also checked against Holmgren and Reveal (1966). Many specimens were identified or verified by either Arthur Holmgren or Leila Shultz of the Intermountain Herbarium, Utah State University, Logan. A number of the better specimens are filed at this institution or the Department of Forestry and Outdoor Recreation, Utah State University. Additional vouchers are deposited at the Intermountain Station Herbarium, Missoula, MT, or the Intermountain Region Herbarium, Ogden, UT.

A number of species presented identification problems for the field crews. *Osmorhiza chilensis* and *Osmorhiza depauperata* are similar vegetatively and positive recognition requires mature fruit (schizocarp). Following the treatment of other workers in the northern and middle Rocky Mountains, these species are lumped as *O. chilensis* on the belief that they are ecologically similar. There also appears to be variability within the *Rosa nutkana-R. woodsii* complex. Both are easy to separate if flowers are present, but our material is most often from shaded stands where *Rosa* reproduces vegetatively. Therefore, the single epithet *woodsii* was used for both. *Artemisia arbuscula* and *A. nova* are apparently sharing morphological attributes when associated with *Pinus ponderosa*. Fluorescence in alcohol, however, indicated a closer affinity with *A. nova*. Following the treatment for Idaho and northern Utah (Steele and others 1981; Mauk and Henderson 1984), the name *Vaccinium globulare* was adopted for type designation and descriptions involving *Vaccinium membranaceum* and *V. globulare*. Occasionally it was necessary to lump graminoids by genus, such as *Poa* and *Carex*, when vegetative material prevented complete identification.

Complicating the taxonomic identification of the central and southern Utah flora is the presence of several converging floristic regimes. The LaSal Mountains, for example, represent a floristic outlier of the southern Rocky Mountains (Cronquist and others 1972). The Pine Valley Mountains in southwestern Utah are at the north ern edge of the Mojavean Desert flora. The northern portion of the study area, principally the Wasatch Plateau contains several species characteristic of the northern Rockies, including *Physocarpus malvaceus*, *Vaccinium globulare*, and *Vaccinium caespitosum*.

SYNECOLOGIC PERSPECTIVE AND TERMINOLOGY

To maintain continuity within the classification effort the following discussion of concept and philosophy is taken, with only minor modification, directly from Pfister and others (1977) and Steele and others (1983).

The Habitat Type Concept

A habitat type is all land capable of producing simila plant communities at climax (Daubenmire and Daubenmir 1968). Because it is the end result of plant succession, the climax plant community reflects the most meaningful integration of environmental factors affecting veget tion. Each habitat type represents a relatively narrow segment of environmental variation and is delineated b a certain potential for vegetational development. Although one habitat type may support a variety of disturbance-induced or seral plant communities, the ulti mate product of vegetational succession anywhere with one habitat type will be similar climax communities. Thus, the habitat type system is a method of site classification that uses the plant community as an indicato of integrated environmental factors as they affect species reproduction and plant community development.

The climax community type provides a logical name for the habitat type, such as *Abies lasiocarpa/Ribes montigenum*. The first part of the name is based on th climax tree species, usually the most shade-tolerant tre species adapted to the site. This level of stratification i called the series and encompasses all habitat types hav ing the same dominant tree at climax. The second part of the name is based on the dominant or most diagnos species in the undergrowth of the climax community.

Use of climax community types to name habitat typ does not imply an abundance of climax vegetation acr the present landscape. Actually, most of the vegetatio within the study area reflects some form of disturbanc and represents various stages of succession towards cl max (refer to the section on "Successional Status"). Habitat type names do not imply that management be directed toward climax vegetation. In most cases, sera species are considered the most productive for timber and wildlife values. Furthermore, this method does not require the presence of a climax stand to identify the habitat type. It can be identified during most stages o succession by comparing the relative reproductive success of the tree species present with known succession trends and by inspecting the existing undergrowth veg tation. During succession, the undergrowth usually progresses toward climax more rapidly than the tree layer. The composition of the undergrowth may becom relatively stable soon after the coniferous canopy close For stands in early successional stages, especially tho

minated by young *Populus tremuloides*, the habitat
pe can often be identified by comparison with adjacent
ature conifer stands having similar topographic and
aphic features.

Habitat types share certain traits with the systematic
xonomy and ecology of plant species. Both habitat
pes and plants have variable characteristics that com-
icate identification of individuals (units of land or
ant specimens). Like plants, closely related habitat
pes share many traits and are distinguished by rela-
vely few prominent features. Individual units of land
ithin a habitat type may display some modal charac-
ristics and traits, but they also have weak affinities to
her habitat types. "Hybrid stands," like plants, are
t uncommon, especially along transitions between
ajor climatic regimes and floristic or physiographic
ovinces. Habitat types have geographic distributions
d geographic variations that follow regional patterns
floristics, climate, and topography. As with many
ant species, endemic and disjunct distributions occur
ithin habitat types.

In developing habitat type classifications, potentially
nportant differential or diagnostic species (indicator
pecies) are evaluated in conjunction with stand charac-
ristics, geographic distribution amplitudes, and zonal
quence of the types. The significance of habitat type
dicators is not the presence of species per se, but
ther their ability to dominate or survive under com-
etition at climax in a segment of their environment.
he opportunity to dominate is determined by the rela-
ve ecological amplitude of species. A species must have
ough amplitude to extend beyond the environmental
mits of its superior competitors. Generally, this results
a species becoming the climax dominant on sites
here the environment is not optimum for the growth of
at species. For example, *Pinus ponderosa* is able to
rvive on sites more droughty than *Pseudotsuga men-*
esii, but is usually more productive on the more mesic
tes that also support *Pseudotsuga*. In general, a spe-
es has the greatest opportunity to become a climax
ominant between its own environmental limits or zone
nd the environmental limits of its superior competitors.
here this climax dominance denotes a relatively small
gment of a species' total ecological amplitude, that
pecies holds high potential as a habitat type indicator.
n other cases, differential species are selected that do
ot attain climax dominance. These species have rela-
ively narrow ecological amplitude and are therefore
seful for indicating that narrow segment of the
nvironment.

The competitive ability of forest species to survive at
limax depends on their reproductive methods, growth
abit, shade tolerance, and possible allelopathic resis-
ance or influence. Most of our coniferous tree species
produce primarily by seed. If seed production and seed
ed conditions are adequate, superior competition is
xpressed through relative reproductive rates and shade
lerance. Many of the undergrowth species, and a few
onifers, can reproduce vegetatively and thereby achieve
n additional competitive advantage. During later suc-
essional stages, vegetative reproduction (rhizomes,
tolons, root-collar sprouts, layering, and so forth) is often a primary factor in maintaining a competitive position. As a result, most species in the forest undergrowth that are selected as habitat type indicators can persist through vegetative reproduction.

In any classification system, intergrades between types exist. A choice exists between extreme concepts of either (1) many narrowly defined types with resultant broad ecotones or (2) a few broadly defined types with narrow ecotones. This habitat type classification for central and southern Utah attempts to achieve a manageable balance among numbers of classified units, natural variation, and application of the taxonomy to field conditions. The written descriptions of types portray modal conditions and emphasize the central characteristics of the type. The key, however, is written in specific terms that narrow the ecotones for field identification. Some variation is recognized within all habitat types. Where possible, phases are defined to reflect major within-type variation. Often, this reduces the geographic, topographic, or edaphic deviation.

In discussing the relationship of a habitat type to certain environmental features, the general polyclimax concept of Tansley (1935) has been followed. Thus, a climatic climax is found on deep loamy soils of gently undulating relief; an edaphic climax develops on the other soils and types of relief, and a topographic climax reflects compensating effects of aspect or different microclimatic effects. Some habitat types are exclusively one type of climax, but most can be found in any category, depending on the interaction of specific environmental features. In steep mountainous terrain, climatic climax sites are generally scarce, with most sites influenced strongly by topographic features such as aspect and slope. However, gentle terrain on the tops of some plateaus within our study area may represent climatic climax sites.

The habitat type classification is useful to forest management in several ways. It provides a permanent and ecologically based system of land stratification in terms of vegetational development (Daubenmire 1976). It also provides a classification system for near-climax forest communities. Each habitat type encompasses a certain amount of environmental variation, but the variation within a particular habitat type is generally less than between types. Thus, successional trends should be predictable for each habitat type and responses to management treatments should be similar on most lands within the same habitat type or phase. This should be most beneficial to the resource manager and land-use planner.

Habitat Type Versus Continuum Philosophy

For many years, ecologists who studied plant communities debated the interpretation of plant community organization. Although there are several philosophies, two extremes have developed: (1) advocates of typal communities argue that distinct vegetational types develop at climax and reappear across the landscape wherever environmental conditions are similar (Daubenmire 1966); (2) continuum advocates argue that even at climax, vegetation, like the environment, varies continuously over the landscape (Cottam and McIntosh 1966). This somewhat academic debate need not preoccupy natural resource managers and field biologists who need a logical, ecologically based environmental classification with which to work. More important is the "usefulness" of recognizing discrete communities and aggregating them into abstract classes or types for the purpose of studying, planning, and communicating (Whittaker 1975; Henderson and West 1977). Therefore, the objective of this classification effort is to develop a logical site classification based upon the natural patterns of potential climax vegetation. Local conditions that deviate from this classification can still be described in terms of how they differ from the typal descriptions presented herein.

THE PHYSICAL SETTING

A majority of the study area (fig. 2) is in the Colorado Plateau Province of the Rocky Mountain system (Fenneman 1931). The Pine Valley Mountains in southwestern Utah are transitional to the Basin and Range Province. Within central and south-central Utah, the Colorado Plateau Province is referred to as the High Plateaus, while southeastern Utah belongs to the Canyon Lands section. The plateaus begin in central Utah at the southern end of the Wasatch Mountains near Nephi on the west and the south end of the Uinta Basin to the east. The plateaus then extend southward almost to the Utah-Arizona border, a distance of about 175 miles (280 km). The western edge is a high scarp dropping into the Basin and Range Province of the western Utah desert while the eastern face overlooks the canyonlands of the Colorado River. Major distinguishing features of the plateaus include a relatively flat tableland with horizontal rocks and broad undulating surfaces, retreating escarpments, and great relief resulting from incision of deep canyons below rather than uplifted mountain ranges (Thornbury 1965). The plateaus are separated from each other by deep trenches containing the Sevier and San Pitch Rivers, Otter, and Soldier Creek. The western section of the Tavaputs Plateau is the most northern of the plateaus and is included in the Ashley National Forest. The Wasatch Plateau is the largest; it and the isolated LaSal and Abajo Mountains of the Canyon Lands section make up the Manti-LaSal National Forest. The Fishlake National Forest contains the southern extreme of the Wasatch Plateau, the Pahvant and Tushar Mountains, and the Fish Lake Plateau. To the south, the Markagunt, Sevier, Paunsaugunt, and Aquarius Plateaus, and the smaller Escalante, Boulder, and Pine Valley Mountains are within the Dixie National Forest.

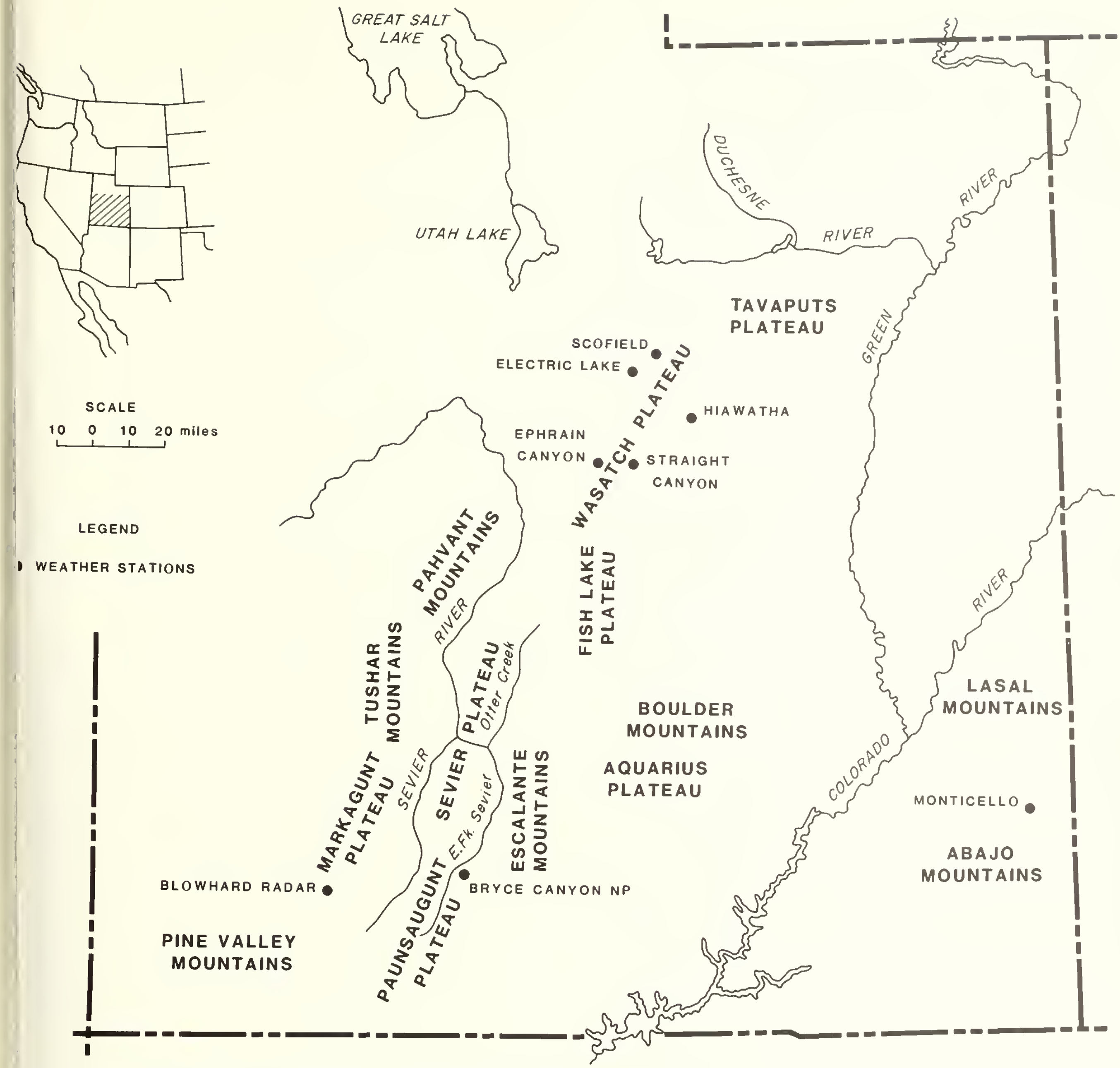
Geology

The narrow east-west trending Tavaputs Plateau forms the southern rim of the Uinta Basin at 8,500 feet (2 590 m). Eocene deposits of lacustrine shale and siltstone predominate. These may contain oil shale, especially in the Parachute Creek member of the Green River Formation (Stokes and Madsen 1961). The Wasatch Plateau rises to over 11,000 feet (3 350 m) and presents a formidable barrier to the westerly storm track. A giant monocline on the west side drops 5,000 feet (1 520 m) to the edge of the San Pitch Valley. Sediments are chiefly Cretaceous and early Tertiary fluvial sandstones and mudstone in the North Horn Formation and limestone in the Frontier Formation. Along the eastern flank, older Cretaceous sediments are exposed, including the Black Hawk Group known for coal production, Mancos Shale, and the Star Point Formation of interbedded sandstone and marine shale (Stokes and Madsen 1961; Hintze and Stokes 1964). The Fish Lake Plateau has elevations similar to the Wasatch, but the sediments have been covered by volcanic extrusions. Late Tertiary basalt and basaltic andesite flows are common (Hintze 1963).

The easternmost plateau is the Aquarius, rising to 11,600 feet (3,530 m). The Boulder Mountains form a subdivision along the northeast side while the Escalante Mountains form the western front. Lava flows are extensive across most of the central Aquarius Plateau. Much of the southern escarpments expose Navajo sandstone of the late Jurassic Period. The Escalante Mountains consist of upper Cretaceous Straight Cliff sandstone, a massive coal-bearing sediment, and sandstone and sandy shale of the Kaiparowits Formation, and Tertiary continental sediments ranging from limestone to coarse conglomerate in the Wasatch Formation (Hintze 1963; Hintze and Stokes 1964). Large areas of the Plateau, mostly at lower elevations, are covered with recent alluvium, landslides, and glacial outwash.

The Sevier and Paunsaugunt Plateaus form the middle section of the High Plateaus and are distinguished by the Sevier Fault extending the entire length along the western side. Sediments on the Paunsaugunt Plateau are similar to the Escalante Mountains; the Wasatch Formation forms the top and Upper Cretacous sandstones are exposed at the escarpments. Results of weathering are vividly displayed along the flanks where Kaiparowits and Wahweap sandstones are eroded away, especially in Bryce Canyon National Park. To the north, the Wasatch Formation conglomerate of the Sevier Plateau has been covered by a thick blanket of andesite-trachyte-latite pyroclastics of early Tertiary time (Hintze 1963). This ash extends outward from the 11,036-foot (3 360-m) top of Mount Dutton.

The western plateaus and mountains are lower in elevation than the eastern section. In the north, the Pahvant Mountains rise to 10,000 feet (3 050 m) and are chiefly composed of Tertiary sediments of the North Horn Formation and Flagstaff Limestone. The crest of the range is white, pink, and yellow quartzite and limestone of Cambrian Period, Paleozoic Era (Hintze 1963). To the south, the Tushar Mountains are mostly volcanic and include tuffs, rhyolite, and latite. Small areas are consolidated conglomerate and volcanic debris. These ar all Pliocene Epoch, Tertiary Period (Hintze 1963). The large Markagunt Plateau is similar to the Sevier, with Wasatch Formation conglomerate covered by lava, andesite flows, latitic ignimbrites, and other Tertiary volcan rock. Both the Wasatch and Kaiparowits Formation are exposed at Cedar Breaks National Monument, where weathering along vertical joints has carved the walls



gure 2.—Area covered by this classification showing major mountain nges and plateaus, drainage patterns, and selected weather stations.

to colonnades of the Pink Cliffs (Fenneman 1931; ornbury 1965).

Along the eastern Utah border, small portions of the anyon Lands Section of the Colorado Plateau Province pport coniferous forests. Two isolated sets of moun- ins included in this study are the LaSals and Abajos; th are giant laccoliths. The northern LaSal Mountains ar Moab have a Tertiary core of porphyritic intrusive cks rising to almost 13,000 feet (3 960 m). Sediments at have been domed up include the Morrison Forma- on of fluvial sandstone and mudstone and Navajo and ayenta Sandstone of Jurassic and Triassic Periods intze and Stokes 1964). Also present are uplifted and ulted glaciated grounds and moraines. The LaSal ountains are in the midst of northwest-trending salt anticlines (Hunt 1958), forming broad deep valleys north, west, and east in Colorado. To the south, the Abajo Mountains are domed up with similar Tertiary intrusions. Subsequent erosion has stripped the overlying sedimentary rocks leaving the igneous core. Sediments on the flanks belong to the Mancos Shale of Upper Cretaceous, Dakota Sandstone, and Burro Canyon Formation of Lower Cretaceous and Morrison Formation of Upper Jurassic. Mount Linnaeus, Twin Peaks, and Horsehead Peak are all near 11,000 feet (3 350 m). To the west along Elk Ridge, lower elevations are older sediments of Navajo Sandstone, Chinle Formation of Jurassic Period, and Cedar Mesa Sandstone of Lower Permian. Deep erosional dissection has created the complex and jumbled topography.

In the extreme southwestern corner of Utah, the Pine Valley Mountains share features of both the Colorado Plateau and the Basin and Range Province (Fenneman 1931). These mountains are formed by the world's largest known laccolith (Cook 1960) and rise to over 10,000 feet (3 050 m). The surrounding sediments are largely the Muddy Creek Formation of tuffaceous sandstone and silt of the Tertiary Period, forming low hills and benchlands. Also present is the Claron Formation of lacustrine limestone conglomerate that resembles the Wasatch Formation of central Utah (Cook 1960).

Glaciation has modified topographic features of many of the higher elevation plateaus and mountains. The Markagunt, Fish Lake, and Wasatch Plateaus apparently had an ice cap during the Wisconsin glaciation (Thornbury 1965). Glaciated ground and moraines are common in the LaSal Mountains, resulting from ice of Pleistocene time (Hunt 1958). The Boulder Mountains, consisting of a fairly flat summit with numerous small lakes, received the most extensive glaciation (Cronquist and others 1972).

Climate

Baker (1944) and Brown (1960) present generalized descriptions of climatic patterns for the mountains of central and southern Utah. Dominant factors influencing the climate include latitude, elevation, position within the Intermountain-Great Basin Region, and distance from the principal moisture sources. Baker (1944) recognized Utah as a region of transition and divided the study area into three subareas. The Wasatch Plateau, especially the west slopes that fall away to the Great Basin, has a continental pattern of high winter snowfall and summer drought and resembles much of the northern Utah mountains. Beginning with the Pahvant Mountains and the Fish Lake Plateau and extending southward, an Arizona-type influence is noticeable, with increased summer precipitation. The east side of the Fish Lake and Aquarius Plateau and the entire LaSal and Abajo Mountains are affected by a pattern resembling that of western Colorado, including a late summer and fall peak in precipitation. Throughout the higher elevations of the study area, the dominant precipitation is in the form of winter and spring snow resulting from Pacific storms. Rainfall from summer thundershowers is usually associated with air masses moving northwest from the Gulf of Mexico or northeast from the Pacific off southern California. Rain shadow effects are common along the Wasatch and Fish Lake Plateaus.

Temperatures vary greatly with latitude and altitude. Inversions are common in some of the lower valleys, especially in the northern portion of the study area. This results from a semipermanent high pressure system that tends to dominate the Great Basin area, particularly during winter months (Brough and others 1983). In general, the diurnal variation in temperatures is relatively large during spring, summer, and fall but is reduced during the winter. Brown (1960) projects a lapse rate of −3 °F mean annual temperature per 1,000 feet increase in elevation (1.7 °C per 305 m) and a corresponding 1.5 to 2.0 °F (0.8 to 1.1 °C) decrease for each degree of latitude northward.

Summer convection storms delivering high-intensity rainfall, aided by orographic lifting, have been the cause of major debris floods within much of the study area. Rainfall intensities as high as 2.2 inches (56 mm) per hour for 20 minutes have been recorded on the Wasatch Plateau (Meeuwig 1960). Many floods have destroyed historic drainage patterns and property, killed livestock and people, and damaged communities at the base of the mountains.

Weather stations (fig. 2) within the study area are rarely situated to obtain long-term data applicable to the forested zone. However, the Ephraim and Straight Canyon watersheds on the Wasatch Plateau are locations of numerous Forest Service research efforts. Data from these and other appropriate stations are discussed by series in the sections on individual attributes of habitat types following type descriptions, and are presented by graphs in appendix H.

SUCCESSIONAL STATUS

Introduced activities such as logging and grazing, as well as changes in wildlife use, have had their effects on the study area.

Logging History

Early logging activities in central and southern Utah were concentrated in the most accessible, lower elevation forests immediately adjacent to small towns and villages, homesteads, and mining operations. Most cutting was indiscriminant, and soil damage may have occurred from the steep drag trails running down the hills. As early as 1870 and into the 1880's, numerous small mills operated along the western base of the Wasatch Plateau, producing railroad ties for the expanding transcontinental railroad. Some of these ties can still be seen in Sanpete County (Haymond 1972). Although sawtimber was abundant in the LaSal and Abajo Mountains, most logging was again intended for local consumption because of the great distances to markets and the primitive nature of transportation systems (Peterson 1975). A former Forest Service policy throughout the area allowed for a free-use system of logging, enabling early settlers to obtain timber for their own buildings, firewood, fencing, and prospecting. Competition for this use was especially concentrated above the growing population centers at the base of the Wasatch, Fish Lake, Markagunt, and Sevier Plateaus. Loggers also apparently set fire to the undergrowth to remove all obstacles and allow easier overstory removal. Many of these fires burned out entire drainages (USDA Forest Service, in prep.).

Following establishment during the first quarter of this century of the National Forests within the study area, the demand for wood products remained relatively constant. Portions of the Boulder Mountains were logged for *Picea engelmannii* following bark beetle epidemics ending around 1930. Much of this material was worked at small saw mills that sprang up throughout western Wayne County (Duane Stewart, Dixie National Forest, pers. comm.). At least 28 mills had operated on the LaSal and Abajo Mountain area prior to 1940 (Peterson 1975), supplying the local ranchers and townspeople with a variety of products on contract.

Finally, during the 1950's in Panguitch, UT, a large-capacity saw mill was established by Crofts-Pearson Industries. This mill, recently sold to Kaibab Industries, is primarily responsible for the dramatic increase in timber harvesting over much of the study area. During the 1950's and early 1960's, much of the *Pinus ponderosa* and *Picea engelmannii* from the Markagunt, Paunsaugunt, Aquarius, and Fish Lake Plateaus was transported to this mill. The principal product was 2-inch lumber (Choate 1965).

As a result of this long period of uncontrolled, piecemeal logging, followed by the more recent large patch or strip clearcutting, old-growth *Pinus ponderosa* stands are especially difficult to find. Closer to the larger communities of Manti, Beaver, and Ephraim, old-growth stands of *Pseudotsuga menziesii* and *Abies concolor* at low elevations are also rare.

Grazing History

The early cultural development of central and southern Utah is closely tied to domestic livestock grazing. Explorers, such as Captain John C. Fremont in 1842 and Major J. W. Powell in 1869, traveled across portions of the study area and noted the available forage for livestock. As early as 1884, almost a complete change in vegetation at Mountain Meadows in the Pine Valley Mountains was attributed to heavy grazing by cattle and then sheep, followed by flash flooding (Cottom 1929, 1961). During the last half of the 19th century, the Wasatch and Fish Lake Plateaus were used extensively by locally owned stock and herds of transient sheep owned by large operations centered outside Utah. It was common for many of the residents of the small communities that were scattered along the valleys to own and maintain small bands of sheep and cows to supplement their agricultural practices (Peterson 1975). There was little control of stock numbers, and sheep were apparently driven into the higher elevations of the mountains while snow was still on the ground (Haycock 1947). Beginning in the early 1900's as the Forest Reserves were transferred from the Department of the Interior to the Department of Agriculture, the predecessors of the current Manti-LaSal, Fishlake, and Dixie National Forests were established. A key issue was the permitting of cattle and sheep. U.S. Department of Agriculture figures show that 1900 was a peak year for sheep in Utah, with 3.8 million in the State; at least 150,000 head of cattle were on the Wasatch Plateau (Haymond 1972). Estimates of the number of sheep for a single grazing allotment on the present-day Fishlake National Forest were as high as 120,000. At sunset, local residents in the valley could count the bands on the mountain by the clouds of dust raised on the bed grounds (Haycock 1947). This number was reduced to about 2,200 sheep by 1919, but severe damage to the resource had already occurred. In an early report to Washington Office supervisors, Reynolds (1911) stated the Wasatch Plateau was "a vast dust bed, grazed, trampled, and burned to the utmost. The timber cover was reduced, the brush thinned, the weeds and grass cropped to the roots, and such sod as existed was broken and worn." Even today, evidence of close trailing, bedding, and burning can be seen on the Wasatch and Fish Lake Plateaus.

Wildlife History

Although most big game use, especially mule deer and elk, is concentrated in mixed shrub and aspen vegetation types within our study area (Julander and Jeffery 1964), the coniferous forests of central and southern Utah have been significantly influenced by wildlife populations. A dramatic increase in mule deer population levels during the 1920's followed a long period of reduced numbers. In 1930, the Fishlake, Manti, and Dixie National Forests reported about 42,500 deer, representing 80 percent of the deer in Utah (Peterson 1975). This trend continued into the 1950's and is at least partly the result of a reduction in domestic grazing permits coupled with the implementation of new grazing systems, and increased brushfields resulting from escaped logging slash fires (Urness 1976).

THE HABITAT TYPE CLASSIFICATION

Thirty-seven forest habitat types within seven series have been defined within the central and southern Utah study area. This seemingly large number of types reflects the environmental diversity resulting from topography, climate, geology, and converging floristic regimes.

For the rest of this publication, the term "habitat type" is abbreviated to "h.t." or "h.t.'s" for the plural. The h.t. names are also abbreviated to the commonly used first two letters of the genus and first two letters of the species of the two plants involved. For example, *Abies lasiocarpa/Ribes montigenum* is reduced to ABLA/RIMO. Complete scientific and abbreviated names of h.t.'s are listed in table 1. Common names are not used within the text to avoid confusion due to variation in local practices or customs.

The classification is presented in the following order:

1. Key to the series, habitat types, and phases: The first step in correct identification of the habitat type is to become familiar with the instructions presented with the key. The key provides an orderly process for first determining the series, then the habitat type, and finally the phase.
2. Series descriptions: Common attributes of habitat types having the same potential climax overstory are summarized at the series level. This also presents a general overview of conditions throughout the series.
3. Habitat type descriptions: Detailed type descriptions summarize the distribution, physical environment, relative abundance, characteristic vegetation, appropriate phasal distinctions, and general management implications.

Table 1.—Central and southern Utah coniferous forest habitat types and phases

Abbreviation	**Habitat Type and Phase**
	***Abies lasiocarpa* Series**
ABLA/ACCO h.t.	*Abies lasiocarpa/Aconitum columbianum* h.t.
ABLA/PHME h.t.	*Abies lasiocarpa/Physocarpus malvaceus* h.t.
ABLA/ACGL h.t.	*Abies lasiocarpa/Acer glabrum* h.t.
ABLA/VACA h.t.	*Abies lasiocarpa/Vaccinium caespitosum* h.t.
ABLA/VAGL h.t.	*Abies lasiocarpa/Vaccinium globulare* h.t.
ABLA/VAMY h.t.	*Abies lasiocarpa/Vaccinium myrtillus* h.t.
ABLA/BERE h.t.	*Abies lasiocarpa/Berberis repens* h.t.
-PIFL phase	-*Pinus flexilis* phase
-PIEN phase	-*Picea engelmannii* phase
-BERE phase	-*Berberis repens* phase
ABLA/RIMO h.t.	*Abies lasiocarpa/Ribes montigenum* h.t.
-MEAR phase	-*Mertensia arizonica* phase
-RIMO phase	-*Ribes montigenum* phase
ABLA/CAGE h.t.	*Abies lasiocarpa/Carex geyeri* h.t.
ABLA/JUCO h.t.	*Abies lasiocarpa/Juniperus communis* h.t.
ABLA/CARO h.t.	*Abies lasiocarpa/Carex rossii* h.t.
	***Abies concolor* Series**
ABCO/PHMA h.t.	*Abies concolor/Physocarpus malvaceus* h.t.
ABCO/ACGL h.t.	*Abies concolor/Acer glabrum* h.t.
ABCO/CELE h.t.	*Abies concolor/Cercocarpus ledifolius* h.t.
ABCO/ARPA h.t.	*Abies concolor/Arctostaphylos patula* h.t.
ABCO/QUGA h.t.	*Abies concolor/Quercus gambelii* h.t.
ABCO/BERE h.t.	*Abies concolor/Berberis repens* h.t.
-JUCO phase	-*Juniperus communis* phase
-BERE phase	-*Berberis repens* phase
ABCO/JUCO h.t.	*Abies concolor/Juniperus communis* h.t.
ABCO/SYOR h.t.	*Abies concolor/Symphoricarpos oreophilus* h.t.
	***Picea engelmannii* Series**
PIEN/RIMO h.t.	*Picea engelmannii/Ribes montigenum* h.t.
	***Picea pungens* Series**
PIPU/EQAR h.t.	*Picea pungens/Equisetum arvense* h.t.
PIPU/JUCO h.t.	*Picea pungens/Juniperus communis* h.t.
PIPU/BERE h.t.	*Picea pungens/Berberis repens* h.t.
	***Pinus flexilis-Pinus longaeva* Series**
	No h.t.'s differentiated
	***Pseudotsuga menziesii* Series**
PSME/PHMA h.t.	*Pseudotsuga menziesii/Physocarpus malvaceus* h.t.
PSME/CELE h.t.	*Pseudotsuga menziesii/Cercocarpus ledifolius* h.t.
PSME/ARPA h.t.	*Pseudotsuga menziesii/Arctostaphylos patula* h.t.
PSME/CEMO h.t.	*Pseudotsuga menziesii/Cercocarpus montanus* h.t.
PSME/QUGA h.t.	*Pseudotsuga menziesii/Quercus gambelii* h.t.
PSME/BERE h.t.	*Pseudotsuga menziesii/Berberis repens* h.t.
-PIPO phase	-*Pinus ponderosa* phase
-BERE phase	-*Berberis repens* phase
PSME/SYOR h.t.	*Pseudotsuga menziesii/Symphoricarpos oreophilus* h.t.
	***Pinus ponderosa* Series**
PIPO/CELE h.t.	*Pinus ponderosa/Cercocarpus ledifolius* h.t.
PIPO/ARPA h.t.	*Pinus ponderosa/Arctostaphylos patula* h.t.
PIPO/ARNO h.t.	*Pinus ponderosa/Artemisia nova* h.t.
PIPO/PUTR h.t.	*Pinus ponderosa/Purshia tridentata* h.t.
PIPO/QUGA h.t.	*Pinus ponderosa/Quercus gambelii* h.t.
-SYOR phase	-*Symphoricarpos oreophilus* phase
-QUGA phase	-*Quercus gambelii* phase
PIPO/SYOR h.t.	*Pinus ponderosa/Symphoricarpos oreophilus* h.t.
PIPO/MUMO h.t.	*Pinus ponderosa/Muhlenbergia montana* h.t.

Total number of series = 7
Total number of habitat types = 37
Total number of habitat types and phases = 43

Arrangement of habitat types within keys tends to progress along the environmental gradient from the least severe to the most severe. Often, the more moist types are encountered before the more moderate. Distributions of h.t.'s are usually illustrated with dot maps. The density of dots on some maps is a function of sampling intensity, as along the northern Wasatch Plateau. Relative abundance of an h.t., as an expression of the amount of land within the study area described by that h.t., is indicated by the terms "incidental," "minor," or "major." An incidental h.t. rarely occurs throughout the study area (therefore no map) but may extend into a portion of the study area from elsewhere. A minor h.t. seldom occurs as large acreages but may be common in the study area with a sporadic occurrence. It may be of major importance to the resource manager as an element of diversity. A major h.t. occupies extensive acreages in at least some portion of the study area. Arrows on some dot maps indicate occurrence of that h.t. beyond the study area. Appendix A lists the actual number of sample stands by habitat type, phase, and general vicinity.

KEY TO SERIES, HABITAT TYPES, AND PHASES

READ THESE INSTRUCTIONS FIRST!

1. Use this key for stands with mature coniferous overstories that are not severely disturbed. If the stand has been recently disturbed by fire, logging, or grazing, or is in an early successional stage, the habitat type can be determined by extrapolation from nearby mature stands on similar sites (same elevation, aspect, geologic material, topographic position, and so forth).
2. Accurately identify and record canopy coverage estimates for all indicator species (appendix I).
3. Record environmental data for plot (appendix I).
4. Identify the correct potential climax tree species using the Key to Climax Series. In general, a tree species is considered successfully reproducing if at least 10 individuals (including established seedlings) per acre occupy or will occupy the site. This often requires careful evaluation.
5. Within the appropriate series key, identify habitat type and phase. The first habitat type or phase in the key that fits the stand, based upon the estimates recorded on the field form, is generally th correct one.
6. Validate the determination by using the habitat typ and phase descriptions and additional information presented in the appendixes.
7. The key is not the classification, but rather a tool t access the classification. Before leaving the stand, validate and record the proper habitat type and phase.

Key to Climax Series

(Do not proceed until you have read the instructions.)

1. *Abies lasiocarpa* present and reproducing successfully	*Abies lasiocarpa* Series (item A)
1. *Abies lasiocarpa* not the indicated climax	2
2. *Abies concolor* present and reproducing successfully	*Abies concolor* Series (item B)
2. *Abies concolor* not the indicated climax	3
3. *Picea engelmannii* present and reproducing successfully	*Picea engelmannii* Series (item C)
3. *Picea engelmannii* not the indicated climax	4
4. *Picea pungens* present and reproducing successfully	*Picea pungens* Series (item D)
4. *Picea pungens* not the indicated climax	5
5. *Pinus flexilis* or *Pinus longaeva* successfully reproducing and dominant, often sharing codominance with *Pseudotsuga*	*Pinus flexilis-Pinus longaeva* Series (no h.t.'s differentiated)
5. *Pinus flexilis* and *Pinus longaeva* absent or clearly seral	6
6. *Pseudotsuga menziesii* present and reproducing successfully ..	*Pseudotsuga menziesii* Series (item E)
6. *Pseudotsuga menziesii* not the indicated climax	7
7. *Pinus ponderosa* present and reproducing successfully	*Pinus ponderosa* Series (item F)
7. *Pinus ponderosa* not the indicated climax	8. Unclassified Series, such as *Populus tremuloides* or *Juniperus scopulorum*

A. Key to *Abies lasiocarpa* Habitat Types

. *Aconitum columbianum, Actaea rubra,* or *Senecio triangularis* at least 1 percent cover	*Abies lasiocarpa /Aconitum columbianum* h.t. (p.17)
. Not as above	2
2. *Physocarpus malvaceus* at least 5 percent cover	*Abies lasiocarpa/Physocarpus malvaceus* h.t. (p.17)*
2. *Physocarpus malvaceus* less than 5 percent cover	3
3. *Acer glabrum* at least 1 percent cover	*Abies lasiocarpa/Acer glabrum* h.t. (p.18)*
3. *Acer glabrum* less than 1 percent cover	4
4. *Vaccinium caespitosum* at least 1 percent cover	*Abies lasiocarpa/Vaccinium caespitosum* h.t. (p.18)*
4. *Vaccinium caespitosum* less than 1 percent cover	5
5. *Vaccinium globulare* at least 5 percent cover	*Abies lasiocarpa/Vaccinium globulare* h.t. (p.19)*
5. *Vaccinium globulare* less than 5 percent cover	6
6. *Vaccinium myrtillus* at least 5 percent cover	*Abies lasiocarpa/Vaccinium myrtillus* h.t. (p.19)
6. Not as above	7
7. *Berberis repens* or *Pachistima myrsinites* at least 1 percent cover	*Abies lasiocarpa/Berberis repens* h.t. (p.20)
7a. *Pinus flexilis* a major overstory component	*Pinus flexilis* phase (p.20)
7b. Not as above, *Picea engelmannii* present	*Picea engelmanii* phase (p.21)
7c. *Picea engelmannii absent*	*Berberis repens* phase (p 22
7. *Berberis* and *Pachistima* less than 1 percent cover	8
8. *Ribes montigenum* at least 1 percent cover, or dominant shrub in normally depauperate undergrowth	*Abies lasiocarpa/Ribes montigenum* h.t. (p.23)
8a. *Mertensia arizonica, Mertensia ciliata, Polemonium pulcherrium, Trifolium longipes,* or *Geranium richardsonii* at least 5 percent cover, collectively or individually	*Mertensia arizonica* phase (p.24)
8b. Not as above	*Ribes montigenum* phase (p.24)
8. *Ribes montigenum* less than 1 percent cover and other shrub dominant in undergrowth	9
9. *Carex geyeri* at least 5 percent cover	*Abies lasiocarpa/Carex geyeri* h.t. (p.26)
9. *Carex geyeri* less than 5 percent cover	10
10. *Juniperus communis* at least 1 percent cover	*Abies lasiocarpa/Juniperus communis* h.t. (p.26)
10. *Juniperus communis* less than 1 percent cover	11
11. *Carex rossii* present, usually at least 1 percent cover	*Abies lasiocarpa/Carex rossii* h.t. (p.27)
11. *Carex rossii* absent	Unclassified conditions

B. Key to *Abies concolor* Habitat Types

1. *Physocarpus malvaceus* at least 5 percent cover	*Abies concolor/Physocarpus malvaceus* h.t. (p.29)*
1. *Physocarpus malvaceus* less than 5 percent cover	2
2. *Acer glabrum* at least 5 percent cover	*Abies concolor/Acer glabrum* h.t. (p.29)
2. *Acer glabrum* less than 5 percent cover	3
3. *Cercocarpus ledifolius* at least 5 percent cover	*Abies concolor/Cercocarpus ledifolius* h.t. (p 30)*
3. *Cercocarpus ledifolius* less than 5 percent cover	4
4. *Arctostaphylos patula* at least 1 percent cover	*Abies concolor/Arctostaphylos patula* h.t. (p.30)
4. *Arctostaphylos patula* less than 1 percent cover	5

5. *Quercus gambelii* at least 5 percent cover	*Abies concolor/Quercus gambelii* h.t. (p.32)*
5. *Quercus gambelii* less than 5 percent cover	6
6. *Berberis repens* at least 1 percent cover	*Abies concolor/Berberis repens* h.t. (p.32)
6a. *Juniperus communis* at least 5 percent cover	*Juniperus communis* phase (p.33)
6b. *Juniperus communis* less than 5 percent cover	*Berberis repens* phase (p.33)
6. *Berberis repens* less than 1 percent cover	7
7. *Juniperus communis* at least 1 percent cover	*Abies concolor/Juniperus communis* h.t. (p.34)*
7. *Juniperus communis* less than 1 percent cover	8
8. *Symphoricarpos oreophilus* at least 1 percent cover	*Abies concolor/Symphoricarpos oreophilus* h.t. (p.34)
8. *Symphoricarpos oreophilus* less than 1 percent cover	Unclassified conditions

C. Key to *Picea engelmanni* Habitat Types

1. *Ribes montigenum* present, usually dominant shrub in normally depauperate undergrowth	*Picea engelmannii/Ribes montigenum* h.t. (p.36)
1. *Ribes montegenum* absent	Unclassified conditions

D. Key to *Picea pungens* Habitat Types

1. *Equisetum arvense, Carex disperma,* or *Glyceria elata* at least 5 percent cover	*Picea pungens/Equisetum arvense* h.t. (p.38)
1. Not as above	2
2. *Arctostaphylos uva-ursi* at least 1 percent cover or *Juniperus communis* at least 5 percent cover	*Picea pungens/Juniperus communis* h.t. (p.3
2. Not as above	3
3. *Berberis repens* at least 1 percent cover	*Picea pungens/Berberis repens* h.t. (p.40)
3. *Berberis repens* less than 1 percent cover	Unclassified conditions

E. Key to *Pseudotsuga menziesii* Habitat Types

1. *Physocarpus malvaceus* at least 1 percent cover	*Pseudotsuga menziesii/Physocarpus malvaceus* h.t. (p.43)*
1. *Physocarpus malvaceus* less than 1 percent cover	2
2. *Cercocarpus ledifolius* at least 5 percent cover	*Pseudotsuga menziesii/Cercocarpus ledifolius* h.t. (p.43)
2. *Cercocarpus ledifolius* less than 5 percent cover	3
3. *Arctostaphylos patula* at least 1 percent cover	*Pseudotsuga menziesii/Arctostaphylos patul* h.t. (p.44)*
3. *Arctostaphylos patula* less than 1 percent cover	4
4. *Cercocarpus montanus* or *Shepherdia rotundifolia* at least 1 percent cover	*Pseudotsuga menziesii/Cercocarpus montanus* h.t. (p.45)*
4. Not as above	5
5. *Quercus gambelii* at least 5 percent cover	*Pseudotsuga menziesii/Quercus gambelii* h.t. (p.45)*
5. *Quercus gambelii* less than 5 percent cover	6
6. *Berberis repens* at least 1 percent cover	*Pseudotsuga menziesii/Berberis repens* h.t. (p.46)
6a. *Pinus ponderosa* present	*Pinus ponderosa* phase (p.46)
6b. *Pinus ponderosa* absent	*Berberis repens* phase (p.46)
6. *Berberis repens* less than 1 percent cover	7
7. *Symphoricarpos oreophilus* present	*Pseudotsuga menziesii/Symphoricarpos oreophilus* h.t. (p.47)
7. *Symphoricarpos oreophilus* absent	Unclassified conditions

F. Key to *Pinus ponderosa* Habitat Types

Cercocarpus ledifolius at least 1 percent cover .... *Pinus ponderosa/Cercocarpus ledifolius* h.t. (p.49)*

Cercocarpus ledifolius less than 1 percent cover 2

2. *Arctostaphylos patula* or *Ceanothus martinii* at least 1 percent .... *Pinus ponderosa/Arctostaphylos patula* h.t. (p.50)

2. Not as above 3

Artemisia nova or *Artemisia arbuscula* at least 5 percent cover or the dominant shrub in normally depauperate undergrowth .... *Pinus ponderosa/Artemisia nova* h.t. (p.50)

Not as above 4

4. *Purshia tridentata* at least 1 percent cover .... *Pinus ponderosa/Purshia tridentata* h.t. (p.52)

4. *Purshia tridentata* less than 1 percent cover 5

. *Quercus gambelii* at least 5 percent cover .... *Pinus ponderosa/Quercus gambelii* h.t. (p.53)

  5a. *Symphoricarpos oreophilus* at least 5 percent cover .... *Symphoricarpos oreophilus* phase (p.53)
  5b. *Symphoricarpos oreophilus* less than 5 percent cover .... *Quercus gambelii* phase (p.54)

. *Quercus gambelii* less than 5 percent cover 6

6. *Symphoricarpos oreophilus* at least 5 percent cover .... *Pinus ponderosa/Symphoricarpos oreophilus* h.t. (p.55)*

6. *Symphoricarpos oreophilus* less than 5 percent cover 7

. *Bouteloua gracilis, Muhlenbergia montana,* or *Oryzopsis hymenoides* at least 1 percent cover, collectively or individually .... *Pinus ponderosa/Muhlenbergia montana* h.t. (p.55)

. Not as above .... Unclassified conditions

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ncidental or minor habitat types in central and southern Utah; may not be listed in other charts and tables.

DESCRIPTIONS OF SERIES, HABITAT TYPES, AND PHASES

Abies lasiocarpa Series

Distribution.—Sites potentially capable of supporting *Abies lasiocarpa* are abundant throughout the entire study area and constitute the *Abies lasiocarpa* series. This series accounts for more than 50 percent of the sample stands used in building the classification. The series is divided into 11 h.t.'s; two have contrasting phases. Our h.t.'s range from the relatively warm and moist (ABLA/ACCO, ABLA/PHMA) to cool and dry (ABLA/JUCO, ABLA/CARO, ABLA/BERE) to cold (ABLA/RIMO). Generally the series represents the middle to upper elevation forested zone. Only the highest portions of the Tushar Mountains and the Aquarius Plateau area exceed the tolerance limits of *A. lasiocarpa*; these sites, if forested, belong to the *Picea engelmannii* series. Elevations within the *Abies lasiocarpa* series range from 8,100 to 11,000 feet (2 470 to 3 350 m). Within this broad belt, topography, parent material, and exposure influence site characteristics, resulting in the diversity of h.t.'s. The series most commonly occurs on steep northern exposures but can also be found on more moderate slopes and other aspects. The warmest and driest sites, if forested, may merge into the *Pinus flexilis-Pinus longaeva* series. Nonforested meadows or shrubfields may be interspersed throughout. Lower bounds of the series will differ locally, with either the *Abies concolor* or *Pseudotsuga menziesii* series adjacent. Occasionally the *Picea pungens* series, and especially the PIPU/EQAR h.t., may be included at lower elevations.

Vegetation.—Most of the central and southern Utah tree species are associates within the series. Although *Abies lasiocarpa* is the climax tree, rarely are pure *A. lasiocarpa* stands found. Instead, *Picea engelmannii*, *Abies concolor*, or *Pseudotsuga menziesii* often are present as persistent seral associates and may contribute greatly to the stand structure. *Populus tremuloides* is almost always an important seral component and may serve as a nurse crop. Only the ABLA/VAMY h.t. usually lacks *P. tremuloides*. Although specific sites may occasionally support scattered *Pinus ponderosa*, the *Abies lasiocarpa* series generally represents environments beyond the temperature limits of *Pinus edulis*, *Juniperus scopulorum*, and *Juniperus osteosperma*.

Undergrowth conditions range from dense, tall shrubs (ABLA/PHMA, ABLA/ACGL) to depauperate (ABLA/RIMO-RIMO, ABLA/BERE-PIEN). Low shrubs usually are used as indicator species. Contrasting conditions are represented by ABLA/ACCO, with diverse forbs, and ABLA/CAGE, in which graminoids dominate.

Soils/climate.—Parent material varies depending upon locale. A few h.t.'s within the series appear on all geologic material, indicating a more zonal or climatic climax. Other h.t.'s, such as ABLA/CAGE, ABLA/JUCO, and ABLA/VAMY, are apparently restricted to volcanics. Depositional material has been influenced by glacial, residual, colluvial, and fluvial actions. As a result this diversity, corresponding surface textures may rang from relatively coarse to fine. Surface rock and bare ground also vary by h.t., with ABLA/BERE-PIFL and ABLA/JUCO representing the most harsh sites. Litter accumulations are relatively constant, averaging 1.3 inches (3.2 cm).

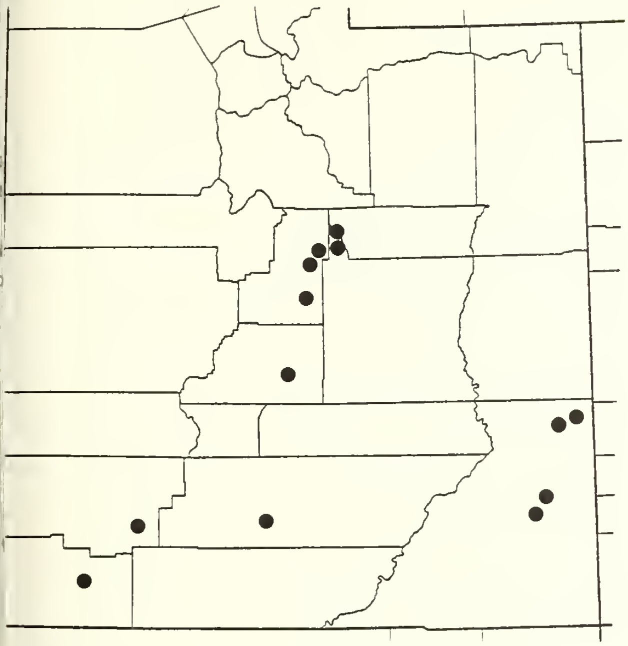
Climatic data for this series are limited because of th lack of year-round recording stations at these elevation The most appropriate information is taken from Ephraim and Straight Canyon watersheds, Electric Lak on the Wasatch Plateau, and Blowhard Mountain on th Markagunt Plateau. In general, sites within this series are cold year-round, with mean annual temperatures below about 37.4 °F (3 °C). Precipitation is predominantly in the form of snow, which may persist until late summer. Frost is possible almost all summer and may be common in restricted topographic basins and benches.

Productivity/management.—Timber potentials range from very low to high and are best described by h.t. O most sites having potential for management, silvicultural prescriptions should favor *Picea engelmannii*. Lower site index and higher susceptibility to root rot (*Fomes annosus* or *Armillaria mellea*) prevent *Abies lasiocarpa* from being intensively managed. Hanley and others (1975) discuss silvicultural implications for management in the uneven-aged stands common in this series. When sites scheduled for overstory manipulation lie adjacent to natural openings such as forb meadows, careful consideration should be given to the potential f invasion by pocket gophers (*Thomomys talpoides*). Eco logical processes and management recommendations ar provided by Teipner and others (1983) and Anderson a MacMahon (1981). Crane (1982) reports on successional pathways and fire effects for sites in Colorado that appear similar to some of our h.t.'s. Most of our types appear to have long natural fire intervals.

Wildlife habitat values within the series are predominantly associated with summer range. Domesti livestock may find little forage in many of the h.t.'s th have depauperate undergrowth. Throughout the series, watershed protection should be a key concern because the late snowmelt.

Other studies.—Our *Abies lasiocarpa* series shares many types common to northern Utah. In addition, a few types are incidental, occurring only in the LaSal ar Abajo Mountains and extending into Colorado. These relationships are discussed by h.t. The central and sou ern Utah study area appears to be the southern extent of several major northern Rocky Mountain h.t.'s; ABLA/PHMA and ABLA/VAGL apparently terminate near the northern edge of the Wasatch Plateau. In con trast, ABLA/BERE and ABLA/RIMO appear to be ce tered within our study area and become progressively less prominent northward.

bies lasiocarpa/Aconitum columbianum h.t. ABLA/ACCO; Subalpine Fir/Monkshood)



Distribution.—ABLA/ACCO is a major h.t. of the *bies lasiocarpa* series and occurs sporadically throughout the entire study area. It represents moist and cool t slopes, steep streamside slopes, and mesic benches. Elevations are generally 8,800 to 10,000 feet (2 700 to 3 050 m), although one sample stand was found as low as 7,380 feet (2 250 m) along a stream bottom. Undulating topography is most common, but concave and straight slopes are also well represented. Exposures are generally northern. ABLA/ACCO can usually be found as relatively large, seepy microsites surrounded by drier h.t.'s such as ABLA/RIMO, ABLA/VAMY, ABLA/CAGE, or ABLA/VACA. Occasionally, it also represents a broad zonal ecotone on steep slopes near drainage bottoms, below the warmer and drier ABLA/BERE or ABCO/BERE h.t.'s.

Vegetation.—*Abies lasiocarpa* is usually present in seral stands and is the indicated climax. *Picea engelmannii* may codominate in seral stands and occasionally be long persistent. *Populus tremuloides* and *Pseudotsuga menziesii* are also seral associates. The dense undergrowth is characteristically forby. A diverse assemblage of tall forbs includes *Aconitum columbianum, Actaea rubra, Delphinium occidentalis, Geranium richardsonii, Senecio triangularis,* and *Thalictrum fendleri*. Common low forbs include *Aquilegia caerulea, Arnica cordifolia, Osmorhiza chilensis,* and *Pyrola secunda*. The most common graminoid is *Bromus ciliatus*. A sparse shrub stratum may often overtop the herbaceous layer and usually is an extension from the adjacent upland communities. *Ribes montigenum* is usually present while other species, depending upon locale, include *Symphoricarpos oreophilus, Vaccinium caespitosum, Vaccinium myrtillus,* and *Pachistima myrsinites. Sambucus racemosa* is also an associate, especially in seral or recently disturbed stands.

Soils.—Our sites have soils derived from a variety of parent materials including both sedimentary and igneous rocks (appendix F). Many sites show the influence of fluvial deposition. This and the expectantly high biomass turnover rates of the undergrowth result in negligible cover of bare ground and exposed rock. Litter accumulations averaged 1.6 inches (4.0 cm), highest for the series. Surface textures are variable, but are predominantly silt loam (appendix G).

Productivity/management.—This h.t. represents the highest potential timber yields for the study area (appendixes D and E). However, many site-specific limitations for management may reduce this expected volume. Steep slopes immediately adjacent to riparian zones or seasonally wet soils will often be major considerations for timber management. On more moderate terrain, shelterwood or group selection systems should maintain the cover, preventing any drastic change in water tables. ABLA/ACCO apparently provides quality summer range habitat for numerous wildlife species, especially big game. Both deer and elk may seek succulent forbs. Water may also be available at seeps or adjacent riparian sites. Squirrels may cache *Picea engelmannii* cones in the cool, moist sites of this h.t.

Other studies.—Mauk and Henderson (1984) describe similar moist sites in northern Utah and name two h.t.'s based upon the presence of *Actaea rubra* or *Streptopus amplexifolius*. Although both are often present on moist sites from our study area and represent the two extremes of the moisture gradient represented by the ABLA/ACCO h.t., it seemed appropriate to select a different species that represented more modal conditions, thereby avoiding confusion with ABLA/ACRU and ABLA/STAM of northern Utah.

Abies lasiocarpa/Physocarpus malvaceus h.t. (ABLA/PHMA; Subalpine Fir/Ninebark)

Distribution.—ABLA/PHMA is an incidental h.t. within our study area, occurring only in the northern portion of the Wasatch Plateau. It is more common in northern Utah, southeastern Idaho, and Wyoming (refer to "Other Studies"). Our sites are typically steep north-facing slopes at middle to low elevations within the *Abies lasiocarpa* zone. Elevations range from 8,200 to 9,350 feet (2 500 to 2 850 m). The type represents the most mesic conditions for the area. ABLA/PHMA is usually bounded by ABLA/ACGL, ABLA/BERE, or PSME/BERE on drier sites. More moist conditions are usually ABLA/ACCO.

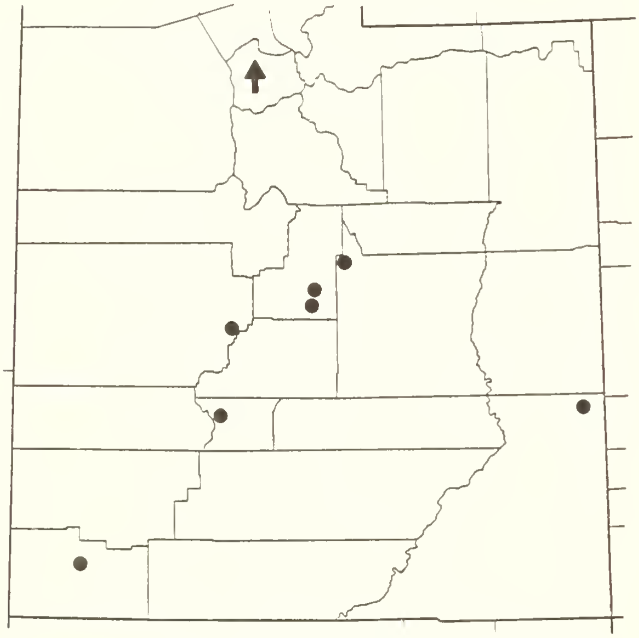
Vegetation.—*Abies lasiocarpa* is the indicated climax tree, but some sites may be dominated by persistent *Pseudotsuga menziesii. Populus tremuloides* and *Picea engelmannii* are also seral associates. The dense undergrowth is dominated by tall shrubs, including *Physocarpus malvaceus, Acer glabrum, Lonicera utahensis,* and *Shepherdia canadensis*. These overtop a low shrub stratum of *Berberis repens, Pachistima myrsinites, Ribes viscosissimum,* and *Symphoricarpos oreophilus*. The herbaceous component is usually relatively sparse and includes only small amounts of *Pyrola secunda, Osmorhiza chilensis, Arnica cordifolia,* and *Carex rossii*.

Soils.—Soils of the ABLA/PHMA h.t. in our study area are all derived from Cretaceous sandstones of marine origin. Litter accumulations average 0.7 inches (1.7 cm). Soils are usually shallow and coarse.

Management/productivity.—ABLA/PHMA presents limited opportunities for timber management. Shallow soils, steep slopes (sampled sites average 65 percent slope), and competition from vegetation will preclude most attempts of stand manipulation. On the most gentle extremes, light shelterwood systems may favor *Picea engelmanii* or *Pseudotsuga*.

Other studies.—ABLA/PHMA is a major type along the Idaho-Utah boundary (Steele and others 1981). Our h.t. follows the same concept developed for northern Utah (Mauk and Henderson 1984).

Abies lasiocarpa/Acer glabrum h.t. (ABLA/ACGL; Subalpine Fir/Mountain Maple)



Distribution.—The ABLA/ACGL h.t. is a minor type in central and southern Utah. Our sample sites are distributed sporadically throughout portions of the Wasatch Plateau and the mountains to the west. It also occurs in the Pine Valley and LaSal Mountains. Sites range in elevation from 8,300 to 9,900 feet (2 530 to 3 020 m) and are usually on steep straight slopes with northern aspects. The type is usually found close to the drier ABLA/BERE h.t.; slightly warmer conditions at the northern end of the Wasatch Plateau may belong to ABLA/PHMA.

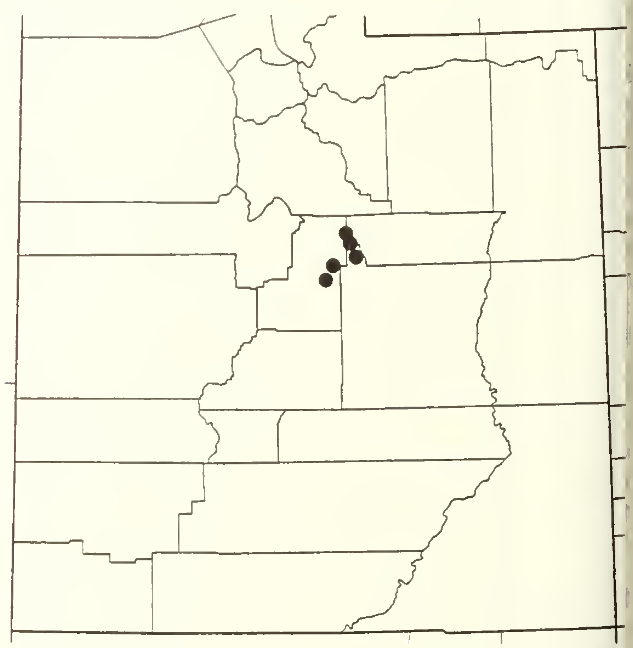
Vegetation.—*Abies lasiocarpa* is the indicated climax tree, but stands may be dominated by other conifers including *Pseudotsuga menziesii, Picea engelmannii, Abies concolor*, or sometimes *Picea pungens. Populus tremuloides* is also an important seral associate. The undergrowth usually consists of multiple strata. *Acer glabrum* and sometimes *Amelanchier alnifolia* create a notable tall shrub layer. A second, lower shrub stratum consists of *Berberis repens, Pachistima myrsinites, Rosa woodsii, Ribes viscosissimum*, and *Symphoricarpos oreophilus*. A diverse forb component includes *Osmorhiza chilensis, Lathyrus lanszwertii, Arnica cordifolia, Thalictrum fendleri*, and *Smilacina stellata*.

Soils.—Our sites are on predominantly Cretaceous and Tertiary sandstone parent material. Sample stands in the Pine Valley and Tushar Mountains had soils derived from andesitic volcanics. Litter accumulations average 1.6 inches (4 cm). Surface textures are mostly loam.

Productivity/management.—Limited data suggest timber yields appear low to moderate and represent relative low potentials for the series. Steep slopes will usually prevent conventional timber management practices. These sites may provide excellent habitat for big game because of the structural diversity and quality browse.

Other studies.—ABLA/ACGL has been described from central Idaho (Steele and others 1981), eastern Idaho and western Wyoming (Steele and others 1983), and northern Utah (Mauk and Henderson 1984). This treatment follows that of northern Utah.

Abies lasiocarpa/Vaccinium caespitosum h.t. (ABLA/VACA; Subalpine Fir/Dwarf Huckleberry)



Distribution.—ABLA/VACA is a minor h.t. in our study area, occurring only in the extreme northern portion of the Wasatch Plateau. However, it may be extensive within this distribution. Our sites belong to the *Picea engelmannii* (PIEN) phase, which serves as a geographical distinction between our study area and other phases of this h.t. in northern Utah and Idaho (refer to "Other Studies"). The ABLA/VACA h.t., PIE phase is found on steep northern slopes at middle to lo elevation within the *Abies lasiocarpa* zone. Our sites anged in elevation from 8,400 to 9,600 feet (2 600 to 000 m), and all had slopes exceeding 45 percent. oundaries with other types are diverse; ABLA/PHMA, BLA/BERE, and PSME/BERE may be on warmer ites while ABLA/RIMO usually represents cooler nvironments.

Vegetation.—*Abies lasiocarpa* is the indicated climax ·ee, although mature stands may often be dominated by *icea engelmannii*. One stand contained *Abies concolor* ıstead of *A. lasiocarpa*, although *A. lasiocarpa* is in the icinity. This plot was placed here rather than the *Abies ncolor* series because all other features were common this h.t. *Populus tremuloides* is an important early ral associate throughout the h.t. The undergrowth is ominated by a dense mat of the low shrub *Vaccinium espitosum*. Other shrubs, usually present in small nounts, include *Pachistima myrsinites*, *Ribes ontigenum*, and *Symphoricarpos oreophilus*. Herbaeous species are negligible; only *Arnica cordifolia*, *athyrus lanszwertii*, *Osmorhiza chilensis*, and *Pyrola cunda* occur with relatively high constancy.

Soils.—All of our sites have Cretaceous sandstone as arent material. Common formations include Star Point, rice River, and the coal-bearing Black Hawk. Bare soil d surface rock are negligible, and litter accumulations erage 1.5 inches (3.9 cm). Other soil data are not availle for this h.t.

Productivity/management.—Timber potentials are oderate (appendixes D and E) and are similar to BLA/RIMO. This h.t. has the highest average site dex for *Abies lasiocarpa* in the study area. However, mber management may be severely limited by slope nstraints. *Picea engelmannii* may be featured by light elterwood or small clearcutting systems. *Populus emuloides* may sucker in response to any major overory manipulation.

Other studies.—ABLA/VACA has been described for ontana (Pfister and others 1977), central Idaho (Steele d others 1981), and the Uinta Mountains in northern tah (Mauk and Henderson 1984). These authors scribe typical sites as gentle slopes and benches with artzitic parent material and glacial outwash basins at collect cold air. *Pinus contorta* is the principal seral ecies and is usually persistent with slow conversion to *bies lasiocarpa*. Our sites, on steep northern slopes th sandstone parent material, support a different tree sociation with *Picea engelmannii* as the principal seral ecies. Differences in undergrowth vegetation also ist. Therefore, the ABLA/VACA h.t. in central Utah is considerably different ecosystem than that described sewhere, and it is distinguished as the PIEN phase.

bies lasiocarpa/Vaccinium globulare h.t. BLA/VAGL; Subalpine Fir/Blue Huckleberrry)

Distribution.—ABLA/VAGL is an incidental h.t., own only from the Huntington Reservoir area on the asatch Plateau. It becomes increasingly important rthward through northern Utah into southern Idaho fer to "Other Studies"). Our sites range in elevation m 9,200 to 9,350 feet (2 800 to 2 850 m) and occurred steep, usually northern exposures.

Vegetation.—The dense overstory of mature stands is composed solely of *Abies lasiocarpa* and *Picea engelmannii*. *Populus tremuloides* may be an early seral associate on some sites. The dense undergrowth is usually dominated by *Vaccinium globulare*, which may be overtopped by *Ribes montigenum* or *Symphoricarpos oreophilus*. *Pachistima myrsinites* is also usually present. *Sambucus racemosa* may persist in undisturbed stands but often increases with any major perturbation. Common herbaceous species include *Carex rossii*, *Bromus ciliatus*, *Arnica cordifolia*, *Osmorhiza chilensis*, and sometimes *Lathyrus lanszwertii*.

Soils.—Soils are derived from Cretaceous and Tertiary sandstone. Litter accumulations average 0.6 inches (1.5 cm). Other data are not available.

Productivity/management.—Although limited data suggest that timber potentials are moderate, this h.t. probably has greater value for watershed protection.

Other studies.—ABLA/VAGL has previously been recognized in Montana (Pfister and others 1977), central Idaho (Steele and others 1981), eastern Idaho and western Wyoming (Steele and others 1983), and northern Utah (Mauk and Henderson 1984). Similar conditions have been described by Kerr and Henderson (1979) on the Wasatch Plateau as the *Abies lasiocarpa/Vaccinium membranaceum* h.t. This description for our study area follows the concept developed for northern Utah.

Abies lasiocarpa/Vaccinium myrtillus h.t. (ABLA/VAMY; Subalpine Fir/Myrtle Whortleberry)

Distribution.—ABLA/VAMY, a minor h.t. of our study area, is locally common only in the LaSal Mountains. It occurs on moderate to steep slopes having northern exposures. Elevations range from 10,000 to 10,600 feet (3 050 to 3 230 m) and generally represent the middle to upper portion of the *Abies lasiocarpa* zone. Adjacent warmer sites usually belong to ABLA/BERE or ABLA/CAGE. Cooler sites most often are within the ABLA/RIMO h.t. Occasionally, ABLA/VAMY will be adjacent to moist seepy microsites that may key to ABLA/ACCO.

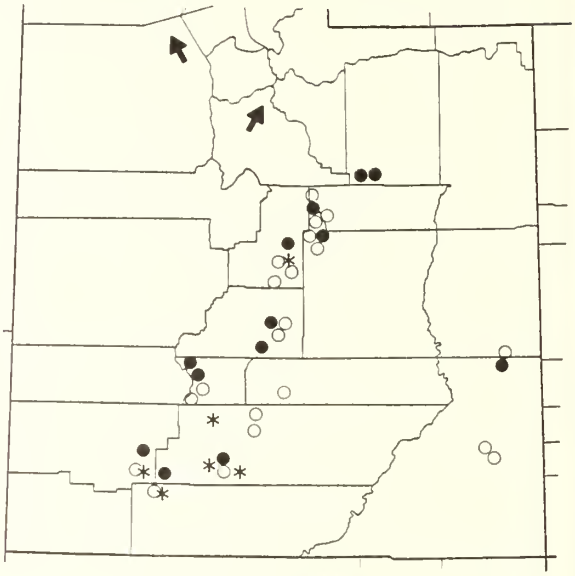
Vegetation.—Mature stands are usually dense and consist of a codominance of *Abies lasiocarpa* and *Picea engelmannii*. *Pseudotsuga menziesii* was observed in one low-elevation stand. ABLA/VAMY is unique for our study area in that *Populus tremuloides* is apparently not capable of tolerating environmental conditions of this h.t. *Populus tremuloides* is a prominent seral component in ABLA/CAGE and also occurs in ABLA/BERE and ABLA/RIMO that may be on similar substrates. Steele and others (1983) noted a comparable relationship with *Vaccinium scoparium* in eastern Idaho and western Wyoming. Limited soil data from the LaSals suggest that litter formed from *Vaccinium myrtillus* may exceed the acidity tolerance of *P. tremuloides*. Once incorporated into the mineral soil, the organic material may lower soil pH values and reduce the lateral extension of *P. tremuloides* roots. Normally, the undergrowth of the ABLA/VAMY h.t. is a dense carpet of the low-growing shrub *V. myrtillus*. This is usually overtopped by scattered *Lonicera involucrata* and *Ribes montigenum*. Herbaceous species include *Bromus ciliatus*, *Arnica* *cordifolia, Lathyrus lanszwertii, Osmorhiza chilensis, Pedicularis racemosa, Polemonium pulcherrimum,* and *Pyrola secunda.*

Soils.—Soils are usually shallow and rocky and are derived from intrusive porphyritics. Bare soil is negligible, but sites may have exposed rock. Litter accumulations average 1.1 inches (2.9 cm), relatively low for the *Abies lasiocarpa* series. Surface textures are predominantly silt loam.

Productivity/management.—Limited timber production data suggest that ABMY/VACA may be similar to ABLA/BERE, PIEN phase for *P. engelmannii* site index (appendix D). Attempts to regenerate *Picea* would be most successful using small clearcut or shelterwood systems. This h.t. may provide important watershed values of delayed snowmelt. Wildlife attributes include summer hiding and thermal cover and limited forage for big game in mature stand conditions.

Other studies.—Our ABLA/VAMY is similar to sites in western Colorado, Arizona, and New Mexico that have undergrowth dominated by *Vaccinium myrtillus* (Hoffman and Alexander 1983; Hoffman and Alexander 1980; Kormarkova 1982; Hess and Wasser 1982; Moir and Ludwig 1979). However, these authors also include *Vaccinium scoparium* in the association along with a variety of other shrubs and moist-site forbs and name the h.t. *Abies lasiocarpa/Vaccinium scoparium.* Often *Picea engelmannii* is added to the name. ABLA/VASC is a widespread and important h.t. of Montana, Idaho, Wyoming, and northern Utah (Pfister and others 1977; Steele and others 1981; Steele and others 1983; Hoffman and Alexander 1976; Mauk and Henderson 1984). Sites in these areas characteristically support *Pinus contorta* as a dominant seral associate. Timber management within the ABLA/VASC h.t. is usually directed toward artificial regeneration of even-aged stands of *P. contorta.* In contrast, our ABLA/VAMY appears sufficiently different because of the apparent lack of *Pinus contorta.* In order to avoid confusion in management implications with the ABLA/VASC h.t. found in the Uinta Mountains, the *Vaccinium myrtillus* epithet was chosen.

Abies lasiocarpa/Berberis repens h.t. (ABLA/BERE; Subalpine Fir/Oregon Grape)



Distribution.—ABLA/BERE is a major h.t. of the middle and northern Rocky Mountains and occurs throughout our study area. It is usually found at middle to lower elevations within the *Abies lasiocarpa* zone. Wide geographic distribution and contrasting environmental characteristics allow the h.t. to be divided into three phases, with differing management opportunities based upon overstory associates. In general, ABLA/BERE occupies relatively cool and dry environments. Elevations range from 8,100 to 10,800 feet (2 470 to 3 290 m), but the type is most often found between 9,000 and 10,000 feet (2 750 to 3 050 m). Aspects are usually northern, with variation discussed by phase. Slopes are gentle to steep, with a variety of configurations. ABLA/BERE is often found below ABLA/RIMO and above either ABCO/BERE or PSME/BERE. Other boundaries are discussed by phase.

Vegetation.—*Abies lasiocarpa* is the indicated climax tree and is often present in early seral stands. *Populus tremuloides* is an important seral species throughout the type. Other associates vary with phase. Mature stands are often dense, with almost complete shading of the undergrowth. A light to moderately dense stratum of shrubs is conspicuous in all phases and includes *Berberi repens, Pachistima myrsinites, Rosa woodsii,* and *Symphoricarpos oreophilus.*

Pinus flexilis (PIFL) phase: The warmest and driest portion of the ABLA/BERE h.t. is represented by the PIFL phase, which occurs on all aspects at middle to upper-elevation positions on straight slopes. The PIFL phase may be adjacent to drier sites belonging to the *Pinus flexilis-Pinus longaeva* series, especially on more southerly exposures. More moist or cooler sites belong to other phases of ABLA/BERE or ABLA/RIMO. This phase can be found throughout the range of the h.t. but is more common in the southern portions of the study area.

Mature stands are older than in the other phases verage age of overstory was 253 years) and usually ontain a mixture of *Abies lasiocarpa*, *Pinus flexilis*, and *seudotsuga menziesii* in codominance (fig. 3). *Picea gelmannii*, if present, will normally be confined to the ost moist and protected microsites. *Abies concolor* or *icea pungens* may be locally abundant, especially on e Markagunt and Paunsaugunt Plateaus. In addition the normal shrub association, *Juniperus communis* nd *Ribes cereum* are usually present. *Amelanchier lnifolia* may account for small coverages. *Ribes ontigenum* is present in small amounts on sites usually bove 9,500 feet (2 900 m), representing colder conditions pproaching the ABLA/RIMO h.t. More graminoids may e present in this phase than others. This stratum sually contains small clumps of *Carex rossii* and scat-ered *Bromus ciliatus*, *Poa fendleriana*, and *Sitanion ystrix*. Forbs are usually inconspicuous; only *stragalus miser*, *Achillea millefolium*, and *Thalictrum fendleri* are present in at least 50 percent of the mature stands.

Picea engelmannii (PIEN) phase: Cooler and more moist portions of the ABLA/BERE h.t. are represented by the PIEN phase. It occurs throughout the range of the type and represents lower to upper portions or straight or concave slopes. Undulating topography can also be found. Exposures are strongly confined to the most northern aspects. Slopes range from gentle to over-steepened and average 42 percent. This phase usually represents a broad ecotone between the BERE phase and colder sites belonging to ABLA/RIMO or PIEN/RIMO. *Pseudotsuga menziesii* and *Picea engelmannii* share a seral role with *Populus tremuloides*. Mature stands are much younger than the PIFL phase; our overstories averaged 161 years. *Abies lasiocarpa* and *Picea engelmannii* are normally codominant in mature and climax conditions.

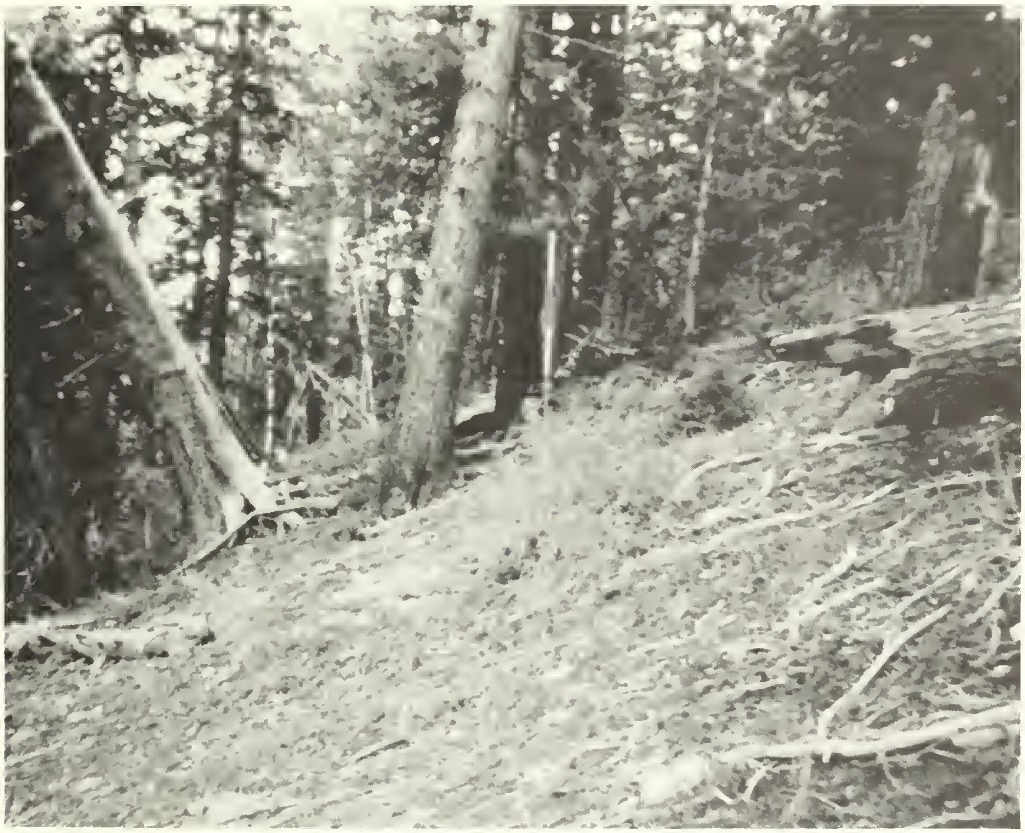


Figure 3.—*Abies lasiocarpa/Berberis repens* h.t., *Pinus flexilis* phase in the Escalante Mountains near Bryce Canyon National Park. The site is on a steep southwest-facing slope at 9,960 feet (3 040 m). *Pseudotsuga menziesii* and *Pinus flexilis* dominate the overstory. *Abies lasiocarpa* and *Picea engelmannii* occur in the understory. Undergrowth species include *Berberis repens*, *Ribes montigenum*, *Bromus ciliatus*, and *Poa fendleriana*.

The dense overstory shades out most undergrowth species (fig. 4). In addition to the normal light shrub association, *Ribes montigenum* may be present, especially on sites above 9,000 feet (2 740 m). Few graminoids are present. Common forbs include *Aquilegia coerulea, Osmorhiza chilensis, Pyrola secunda*, and *Thalictrum fendleri. Lathyrus lanszwertii* may occur in seral stands under *Populus tremuloides. Arnica cordifolia* may be found on sites on the Wasatch Plateau.

Berberis repens (BERE) phase: The modal portion of the h.t. occurs on moderate to steep lower to middle slopes throughout the range of the h.t. It represents cool and dry conditions in between the other phases. Exposures are usually northwest to northeast. In addition to other phases of the ABLA/BERE h.t., this phase may be bounded by ABLA/JUCO, ABLA/RIMO, or PIEN/RIMO on colder sites. Adjacent warm sites usually belong to PSME/BERE, ABCO/BERE, or the *Picea pungens* series.

Both *Pseudotsuga menziesii* and *Populus tremuloides* are important seral species. *Picea pungens* and *Abies concolor* are locally common. Mature to climax stands (ours averaged 122 years old) may be dominated solely by *Abies lasiocarpa*. In addition to the light shrub stratum listed for the h.t., *Juniperus communis* and the graminoids *Carex rossii* and *Bromus ciliatus* are usually present. Common forbs include *Thalictrum fendleri, Osmorhiza chilensis, Astragalus miser*, and *Achillea millefolium. Lathyrus lanszwertii* is common in seral stands.

Soils.—Our ABLA/BERE is usually found on colluvium or residual material derived from limestone or sandstone parent materials (appendix F). All three phases occur most often on the Wasatch Formation, a continental deposit of coarse conglomerate, sandstone, and limestone from the Tertiary Period. Both the PIEN and PIFL phases also occur on other Tertiary and Cretaceous sandstone rocks, including the North Horn, Star Point, and Black Hawk Formations. A few sites in each phase are also of igneous origin, especially in the Abajo and LaSal Mountains and the Aquarius Plateau. The Mount Dutton area of the Sevier Plateau and the Delano Peak area in the Tushar Mountains are of mixed volcanic origin, with BERE and PIFL phases commonly represented. In general, soils are normally shallow and coarse. Surface textures range from sandy loam to clay loam. Bare soil and exposed rock are common; amounts of exposed rock and boulders may be as high as 40 percent in the PIEN phase. Areas of bare soil averaged 12 percent in the PIFL phase and less for other phases.

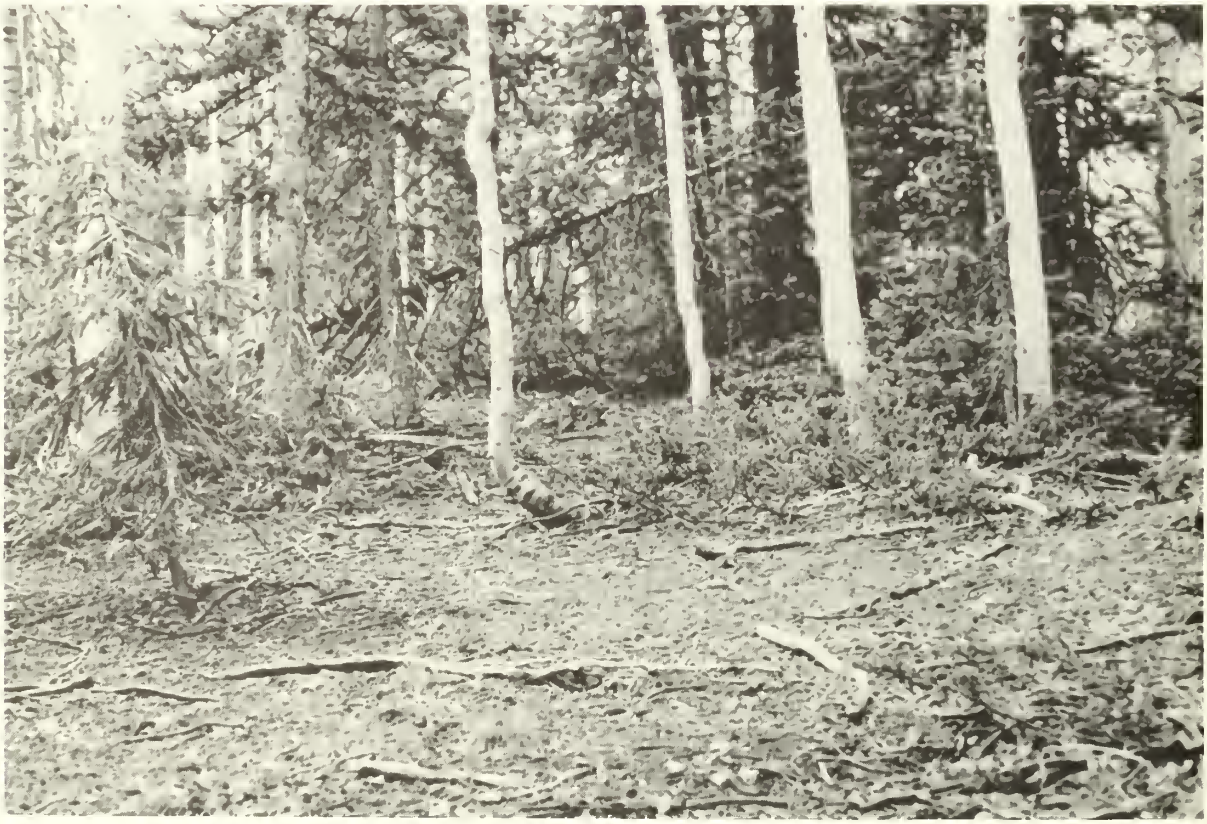


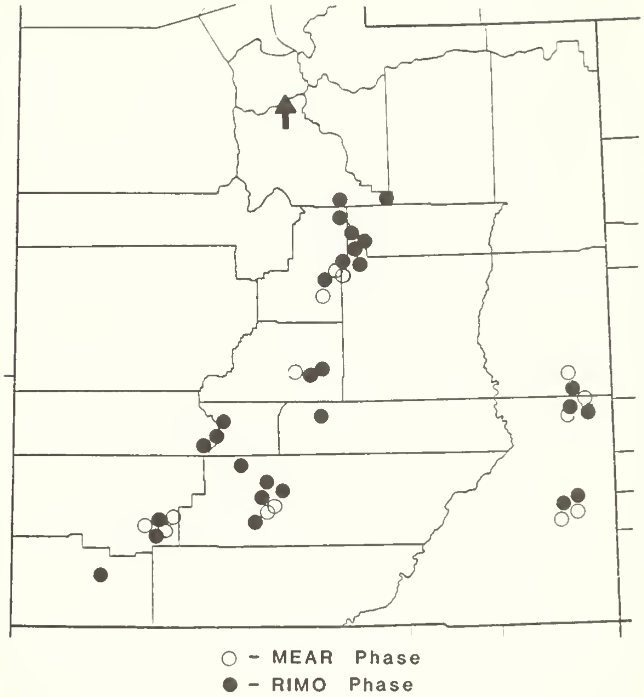
Figure 4.—*Abies lasiocarpa/ Berberis repens* h.t., *Picea engelmannii* phase on a cool, flat bench north of Navajo Lake on the Markagunt Plateau (9,600 feet, 2 930 m). *Abies lasiocarpa, Picea engelmannii*, and remnant *Populus tremuloides* comprise the overstory. The undergrowth contains small amounts of *Berberis repens, Ribes montigenum*, and *Carex rossii*.

Litter accumulations average 1.3 inches (3.3 cm) for BERE and PIEN phases but only 0.9 inch (2.4 cm) for the PIFL phase.

Productivity/management.—Timber potentials range from low to moderate and vary with phase (appendixes D and E). Yields are highest in the PIEN phase and lowest in the PIFL phase. Both PIEN and BERE phases represent areas having potential for timber management if sound silvicultural prescriptions are applied. *Picea engelmannii* and *Pseudotsuga menziesii* may be favored by light shelterwood or small clearcutting systems in the PIEN phase. *Picea pungens* may be the most productive species to feature in the BERE phase, if it is common locally. The PIFL phase may represent sites with values other than timber production; lack of regeneration success and slow growth rates should preclude most stand manipulations. Throughout the h.t., opportunities exist for managing aspen, especially for wildlife habitat values such as increased forage and browse for deer. Elk may also use these sites extensively during the summer. The BERE and PIEN phases represent areas of prolonged snowpack accumulation and thus may be important for watershed protection.

Other studies.—ABLA/BERE was first described in Utah by Pfister (1972). He found the same common association of four shrubs and designated them the *Berberis repens* union. His concept of the ABLA/BERE h.t. is broader than this h.t.; it includes our ABLA/ACGL, all three phases of our ABLA/BERE, ABLA/CAGE, ABLA/JUCO, and ABLA/CARO, and portions of ABLA/RIMO. Pfister suggested three phases to subdivide the h.t., based upon presence or absence of *Ribes montigenum* and *Picea engelmannii*. His *Ribes montigenum* phase represented highest elevation sites and his *Abies lasiocarpa* phase described lowest elevation conditions. Our concept of the h.t. and phases follows that of northern Utah (Mauk and Henderson 1984), with a PIFL phase for dry exposures and a BERE phase for modal conditions. The use of *Picea engelmannii* rather than *Ribes montigenum* for a phasal break was based upon the similarity of stand conditions and the anticipated resource interpretations concerning timber management. The ABLA/BERE h.t. has also been described from southeastern Idaho and western Wyoming (Steele and others 1983) and the northern portion of the Wasatch Plateau (Kerr and Henderson 1979).

Abies lasiocarpa/Ribes montigenum h.t. (ABLA/RIMO; Subalpine Fir/Mountain Gooseberry)



Distribution.—ABLA/RIMO is common at middle to upper elevations of the *Abies lasiocarpa* zone and can be found in vast acreages on most of the high plateaus and mountains of central and southern Utah. It also extends northward into Idaho and Wyoming (refer to "Other Studies"). It accounts for almost one quarter of our sample stands. Our sites generally range in elevation from 9,500 to 11,000 feet (2 400 to 3 350 m) and are usually on northwest to northeast exposures. Other site characteristics are discussed by phase below.

Vegetation.—Mature or old-growth stands are dominated by both *Abies lasiocarpa* and *Picea engelmannii*. Both are often layering in the understory. Stands range from large and continuous to rather patchy or clumpy, interspersed with open meadow. *Populus tremuloides*, an important early seral associate, is usually present in mature or old growth conditions only as remnant stems of poor vigor. Occasionally, only downed logs indicate the previous stand of *P. tremuloides*. Sample stand data suggest the following generalized successional sequence for this h.t. Following a major stand-destroying disturbance such as natural fire, remnant *P. tremuloides* root systems resprout, creating a clone. Invasion of *Abies lasiocarpa* follows, and saplings may develop quickly under this nurse crop of *P. tremuloides*. Invasion of *Picea engelmannii* is much slower and may be restricted to areas of bare soil. Pfister (1972) suggests this progression to a pure *Abies-Picea* climax may require at least 1,000 years without additional disturbance. The eventual uneven-aged climax stand usually has abundant *A. lasiocarpa* seedlings and saplings in addition to vegetative layering. *Picea engelmannii*, although common in the overstory, is usually present in the understory on raised root mounds and depressions resulting from windthrow of the shorter lived *A. lasiocarpa* following root rot. Thus, the regeneration is confined to gaps created in the overstory.

Undergrowth vegetation is distinguished by two phases.

Mertensia arizonica (MEAR) phase: The MEAR phase represents the most hydric extent of the h.t. It is found throughout the distribution of the type in our study area but appears to be best represented in the Cedar Breaks area on the Markagunt Plateau. It generally occurs at the highest elevations within the type; our sample stands are usually above 10,000 feet (3 050 m). This phase may also be found on a wide variety of aspects in addition to the most northern exposures. Slopes or swales are usually gentle to moderate and are either straight or concave. Abundant ground moisture is apparently present throughout the growing season as a result of snowpack accumulations on lee slopes and numerous seeps and small springs. The MEAR phase is usually found above the RIMO phase of the ABLA/RIMO h.t. It often is patchy or broken, with graminoid-forb meadows surrounding. The PIEN/RIMO h.t. occasionally may abut, forming the upper boundary.

Total undergrowth canopy cover is about 40 percent, creating a relatively lush, dense ground cover. *Ribes montigenum* is conspicuous throughout the stand (fig. 5). The diverse herbaceous stratum contains numerous moist-site forbs, including *Mertensia arizonica*, *Mertensia ciliata*, *Geranium richardsonii*, *Polemonium pulcherrimum*, and *Trifolium longipes*. Other common species include *Achillea millefolium*, *Aquilegia coerulea*, *Arnica cordifolia*, *Delphinium barbeyi*, *Epilobium angustifolium*, *Osmorhiza chilensis*, *Pyrola secunda*, *Thalictrum fendleri*, and *Carex rossii*.

Ribes montigenum (RIMO) phase: Modal conditions are represented by the RIMO phase. It occurs most often on gentle to steep straight slopes with northern exposures. Our sample stands are most often at elevations between 9,500 and 10,500 feet (2 900 to 3 200 m). The RIMO phase may represent either climatic or topoedaphic climaxes depending upon locale. Many sites on steep northern slopes are above a wide variety of other h.t.'s, including ABLA/BERE-PIEN, ABLA/VACA, ABLA/VAMY, ABLA/CAGE, or ABLA/CARO. On more gentle undulating terrain, such as the relatively flat tops of some plateaus, this phase may be extensive. Higher and colder sites that support conifers are described by the PIEN/RIMO h.t.

A normally sparse undergrowth (fig. 6) contains a light, scattered canopy of *Ribes montigenum*, usually confined to near the base of large trees. Other shrubs, including *Sambucus racemosa*, *Symphoricarpos oreophilus*, and *Shepherdia canadensis*, may occur in openings or on recently disturbed areas. The depauperate herbaceous stratum includes *Thalictrum fendleri*, *Osmorhiza chilensis*, *Arnica cordifolia*, *Achillea millefolium*, and *Carex rossii*. Under disturbed conditions, or in seral stands with incomplete conifer canopies, *Lupinus argenteus*, *Lathyrus lanszwertii*, *Helenium hoopsii*, *Epilobium angustifolium*, *Aquilegia coerulea*, and *Achillea millefolium* are expected to increase.

Soils.—Because of its wide distribution, ABLA/RIMO is found on a variety of parent materials (appendix F). Bare soil and exposed rock average about 5 percent for both phases but can range as high as 45 percent in the RIMO phase and 30 percent in the MEAR phase. Litter accumulations average 1.2 inches (3 cm) for both phases Major distinctions between phases exist in surface textures; MEAR is predominantly silt loam and clay loam, while the RIMO phase is often as coarse as sandy loam (appendix G).

Productivity/management.—Timber potentials vary slightly by phase but generally represent the best opportunities for management within the *Abies lasiocarpa* series (appendixes D and E). Management will usually feature *Picea engelmannii* as the most productive species. In general, silvicultural prescriptions should include a careful consideration of the natural uneven-aged structure and the inability for *P. engelmannii* to regenerate without site protection. Throughout the study area, numerous examples of natural and artificial regeneration failures in large clearcuts indicate the need to provide partial protection for seedling survival. Small clearcuts, shelterwood, or group or individual tree selection methods should be designed to prevent seedling mortality from frost, desiccation from winter winds, sun scald, and soil movement. The MEAR phase may have additional constraints on overstory removal because of the apparent depth of the water table. As with PIEN/RIMO the degree of slash removal in ABLA/RIMO must be

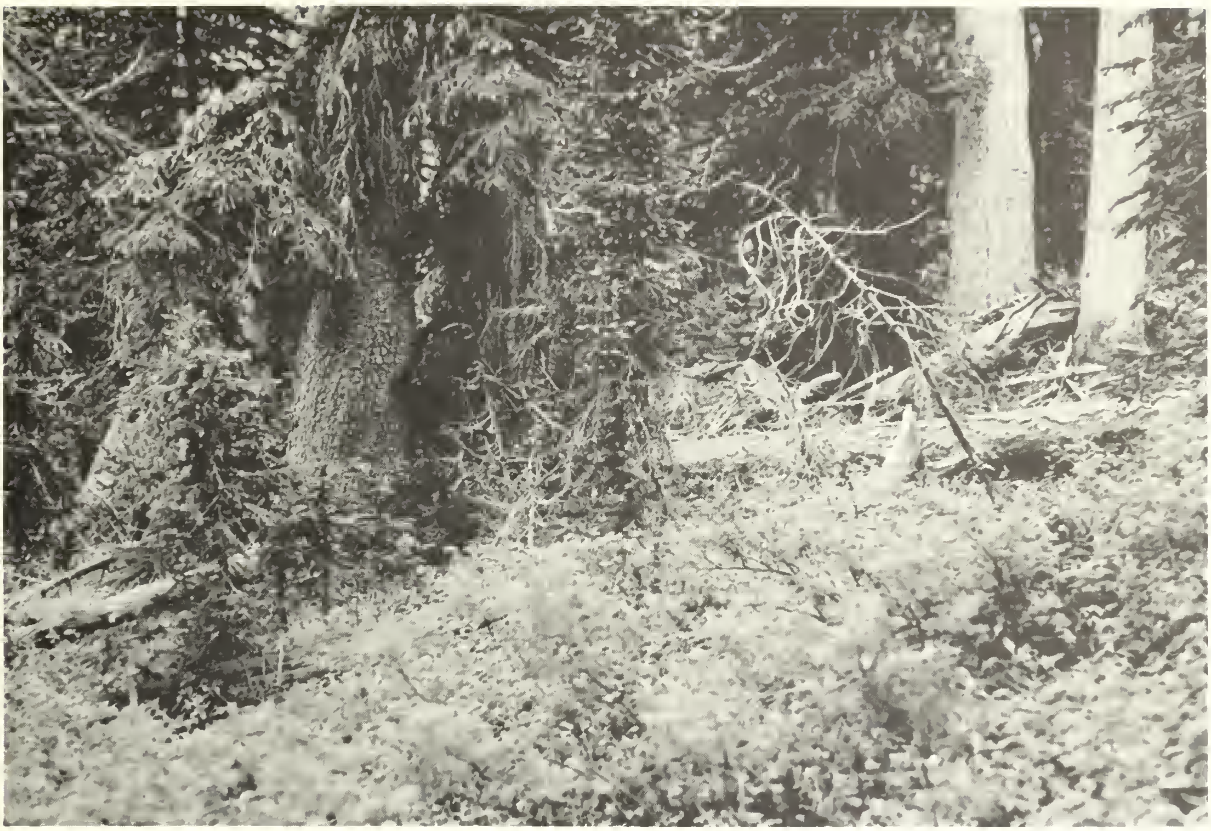


Figure 5.—*Abies lasiocarpa/ Ribes montigenum* h.t., *Mertensia arizonica* phase on a moderately steep north slope near North Creek Pass (10,200 feet, 3 100 m) in the Abajo Mountains. *Abies lasiocarpa* and *Picea engelmannii* are the only trees on the site. The dense undergrowth contains *Ribes montigenum* and a diverse assemblage of forbs.

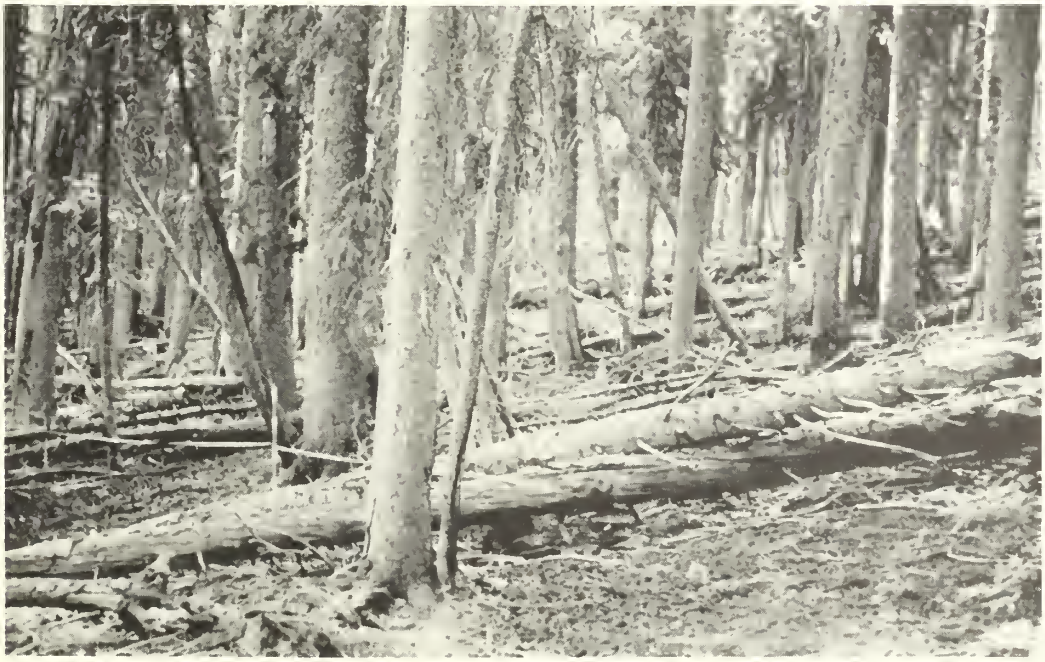


Figure 6.—*Abies lasiocarpa/ Ribes montigenum* h.t., *Ribes montigenum* phase on a moderately steep northeast slope (10,480 feet, 3 200 m) of Mount Mellenthin in the LaSal Mountains. *Abies lasiocarpa* and *Picea engelmannii* are the only trees on the site. The depauperate undergrowth is dominated by scattered *Ribes montigenum* and *Osmorhiza chilensis.*

carefully balanced between site amelioration values and host sites for bark beetles (*Dendroctonus rufipennis*). *Abies lasiocarpa* is almost uniformly susceptible to decay by *Fomes annosus*, which increases the chances of windthrow. Many of our stands contained *A. lasiocarpa* infected with the yellow witches' broom rust (*Melampsorella caryophyllacearum*).

Domestic livestock will usually find little forage in mature stands belonging to the RIMO phase, but abundant succulent forbs in the MEAR phase may attract sheep. Deer and elk use is high in both phases; this h.t. may function as prime summer range. Many stands within the MEAR phase contain large squirrel caches.

Watershed protection is a principal resource value. Snow is often retained as late as August on the higher elevation sites.

Other studies.—ABLA/RIMO is a major h.t. through the Rocky Mountains, with descriptions for Montana (Pfister and others 1977), central Idaho (Steele and others 1981), eastern Idaho and western Wyoming (Steele and others 1983), and northern Utah (Mauk and Henderson 1984). Pfister (1972) originally described the h.t. for our study area and proposed three phases based upon the presence of (1) *Ribes montigenum*, (2) *Thalictrum fendleri*, or (3) *Lonicera involucrata*. Additional phases have been reported for northern Utah and Wyoming. This classification includes the mesic portions of Pfister's *Lonicera involucrata* and *Thalictrum fendleri* phases in the MEAR phase, while the modal RIMO phase comprises the remaining *Ribes montigenum* stands and the high-elevation portions of his *Abies lasiocarpa/Berberis repens* h.t.

Abies lasiocarpa/Carex geyeri h.t. (ABLA/CAGE; Subalpine Fir/Elk Sedge)

Distribution.—ABLA/CAGE is an incidental type in the LaSal and Abajo Mountains, but it also occurs in central Colorado (refer to "Other studies"). Our sites range from 8,800 to 9,800 feet (2 700 to 3 000 m) in elevation on mesic gentle slopes and benches. Exposures are northwest to northeast. Adjacent drier sites may belong to ABLA/BERE, while cooler sites usually belong to ABLA/RIMO or ABLA/VAMY.

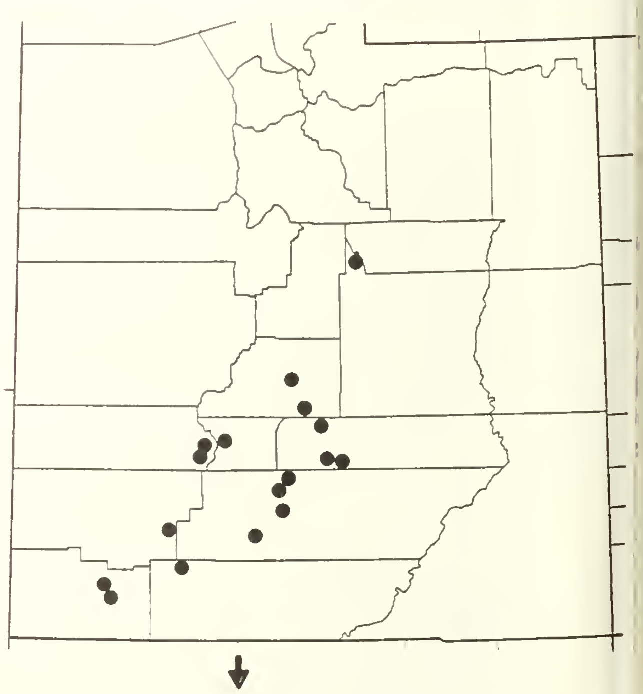
Vegetation.—Mature or climax stands are dominated by *Abies lasiocarpa*. *Picea engelmannii* may also be present in small amounts as a persistent seral associate. *Populus tremuloides* is the dominant seral component and was present in all our sample stands. The undergrowth is characterized by a relatively dense sward of *Carex geyeri*. This may be overtopped by scattered low shrubs, including *Berberis repens*, *Rosa woodsii*, and *Symphoricarpos oreophilus*. Forbs include *Achillea millefolium*, *Lathyrus lanszwertii*, *Osmorhiza chilensis*, and *Smilacina stellata*.

Soils.—ABLA/CAGE is apparently restricted to igneous parent materials in our study area. Soils were developed in residual material derived from intrusive porphyritics. Bare soil and exposed rock or boulders are negligible. Litter accumulations averaged 1.2 inches (3.1 cm). Textures are loam or silt loam.

Productivity/management.—Timber potentials are apparently moderate to high. Limited site index data for *Picea engelmannii* indicate it perhaps should be favored. Dense sod of *Carex geyeri* will prohibit natural regeneration unless sites are scarified. *Populus tremuloides* may also present opportunities for management. Both deer and cattle should find forage on these sites.

Other studies.—ABLA/CAGE was first described by Pfister and others (1977) in Montana as a minor type. It also occurs in central Idaho (Steele and others 1981), from Yellowstone National Park southward to southeastern Idaho (Steele and others 1983), and in southeastern Wyoming (Wirsing and Alexander 1975). These authors list both *Populus tremuloides* and *Pinus contorta* as principal seral associates. Our h.t. has closer affinities with ABLA/CAGE that is found on the Routt and White River National Forests of north-central Colorado, where *Pinus contorta* is not a component (Hoffman and Alexander 1983; Hoffman and Alexander 1980; Hess and Wasser 1982). Similar conditions also apparently exist on the Gunnison and Uncompahgre National Forests of western Colorado (Komarkova 1982).

Abies lasiocarpa/Juniperus communis h.t. (ABLA/JUCO; Subalpine Fir/Common Juniper)



Distribution.—A major h.t. of the southern portion of ur study area, ABLA/JUCO occupies middle to upper evation slopes, ridges, and benches on all aspects. Our tes ranged from 8,800 to 10,600 feet (2 680 to 3 330 m) ı elevation, but most were above 9,500 feet (2 900 m). opography may be straight, undulating, or convex. lopes vary from gentle to steep and average 21 percent. BLA/JUCO is usually on warmer aspects or elevations ıan ABLA/ RIMO or ABLA/CARO, while BLA/BERE represents slightly more mesic conditions.

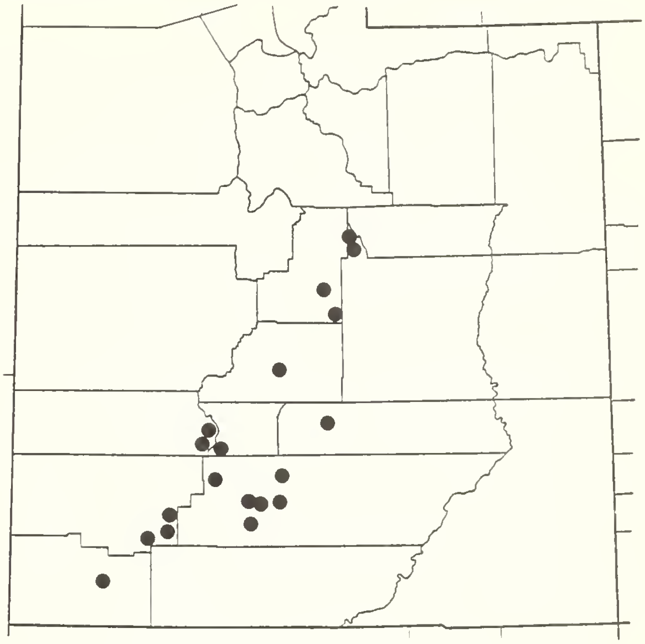
Vegetation.—*Abies lasiocarpa* is the indicated climax ee and is usually present in early seral to mature ands. Both *Picea engelmannii* and *Populus tremuloides* ·e important seral associates. Both *P. engelmannii* and . *lasiocarpa* may layer in the understory. *Pseudotsuga enziesii* and *Picea pungens* may also be present as ·ral but persistent associates. The patchy undergrowth dominated by *Juniperus communis*, which may ·velop into large horizontal clumps. Other common ırubs include *Rosa woodsii, Symphoricarpos oreophilus*, ıd occasionally *Berberis repens*. Site characteristics and ›undance of *B. repens* should be carefully assessed in ·der to distinguish between this h.t. and ABLA/BERE, [EN phase. In general, ABLA/JUCO is much more ›pauperate than ABLA/BERE.

Soils.—ABLA/JUCO occurs on soils derived almost xclusively from igneous parent materials, primarily asaltic flows (appendix F). Most sites have rocky surıces with abundant bare soil. Litter accumulations average 1 inch (2.5 cm). Surface textures are predominantly andy loam and loam (appendix G).

Productivity/management.—Timber potentials are enerally low (appendixes D and E). This h.t. represents ıe lowest potential yields for the series. Natural ›generation appears to be sporadic and limited to only ıe most mesic microsites. Normal or standard proceures of manipulating the overstory for silvicultural purposes will usually be unsuccessful. Wildlife, especially ig game, may find both cover and forage or browse on ıese sites, but most use will probably be associated ith proximal plant communities.

Other studies.—Similar conditions exist in Idaho and /yoming (Steele and others 1981, 1983) where the type so occurs along cold air drainages. These sites also ıpport *Pinus contorta*. Along the Uinta Mountains orth of our study area, sites supporting predominantly *uniperus communis* occur and are included within the *bies lasiocarpa/Berberis repens* h.t. (Mauk and enderson 1984). Our sites show the most affinity to ›nditions described for the North Kaibab Plateau and ountains of northern New Mexico (Moir and Ludwig)79).

Abies lasiocarpa/Carex rossii h.t. (ABLA/CARO; Subalpine Fir/Ross Sedge)



Distribution.—ABLA/CARO is a major h.t. of the *Abies lasiocarpa* series and can be found throughout the study area with the exception of the eastern LaSal and Abajo Mountains. The type commonly occurs on flat benches to straight and steep northern slopes at middle to upper elevations. Our sites ranged from 8,600 to 10,400 feet (2 620 to 3 170 m), but the type is most common above 9,500 feet (2 900 m). ABLA/CARO apparently represents sites drier than ABLA/BERE and slightly warmer than ABLA/RIMO.

Vegetation.—Mature or climax stands are relatively dense and are codominated by *Abies lasiocarpa* and *Picea engelmannii*. *Abies lasiocarpa* reproduction may also be present in the understory as vegetative layering. *Pseudotsuga menziesii* is locally important as a seral associate, especially on the Wasatch and Fish Lake Plateaus and the Tushar Mountains. Throughout the h.t., *Populus tremuloides* is an important seral associate and usually serves as a nurse crop for conifer regeneration. The undergrowth is depauperate (fig. 7), with only a light coverage of *Carex rossii* representing a diagnostic feature. Other species that may also occur that are usually associated with small openings include *Arnica cordifolia, Astragalus miser*, and *Rosa woodsii*.

Soils.—Parent materials depend upon locale and include limestone, Cretaceous sandstone, andesite, and most often basalt (appendix F). Both surface rock and bare soil are variable and may range from none to almost 50 percent. Litter accumulations average 1.4 inches (3.5 cm). Surface soil textures are mostly sandy loam and loam (appendix G).

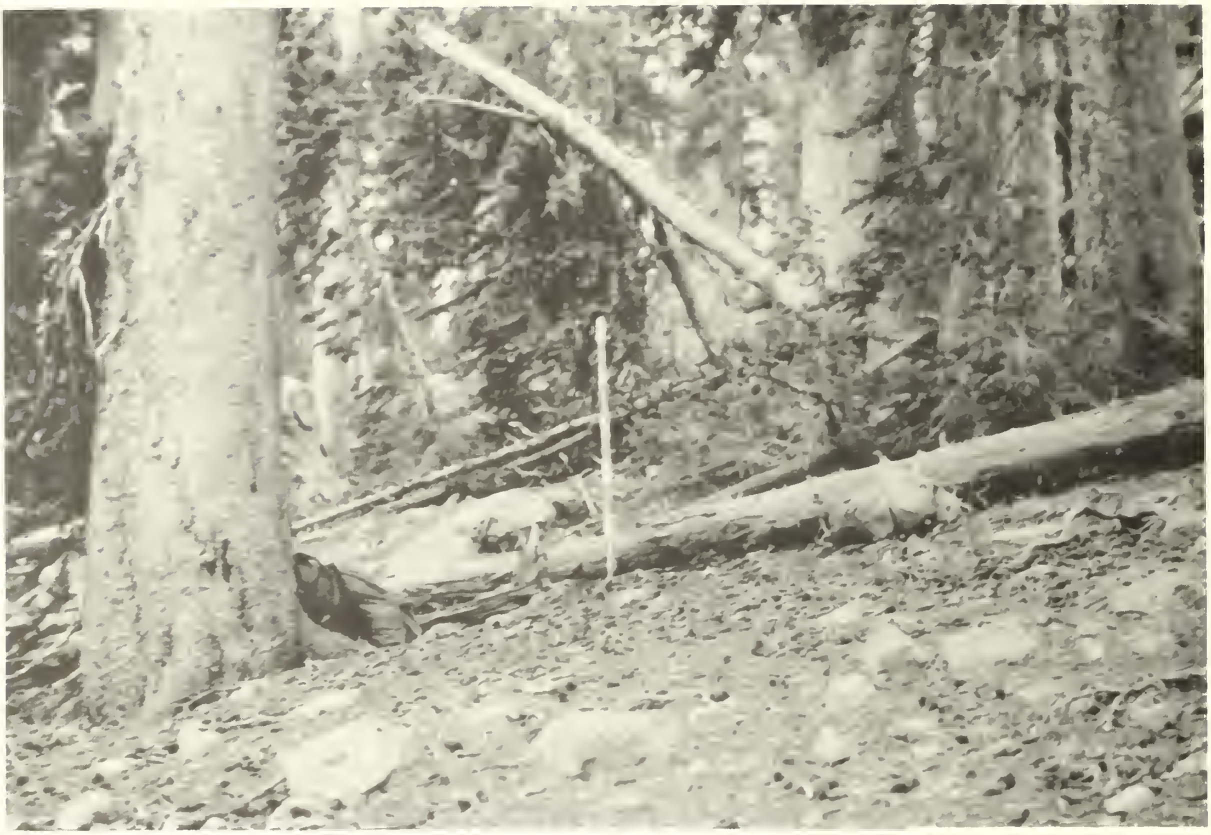


Figure 7.—*Abies lasiocarpa/Carex rossii* h.t. on a moderately steep, northeast-facing slope (9,760 feet, 2 980 m) near New Harmony in the Pine Valley Mountains. *Picea engelmannii* and *Abies lasiocarpa* dominate the mature overstory. *Abies lasiocarpa* is layering in the understory. *Carex rossii* is the major component of a depauperate undergrowth.

Productivity/management.—Timber potentials are generally moderate (appendixes D and E) and are about average for the series. Successful silvicultural prescriptions for *Picea engelmannii* will likely involve small openings that maintain site protection. Many of our sites contain *Abies lasiocarpa* infected with the root rot *Fomes annosus*. According to Steele and others (1983), the root system of established *Carex rossii* may be sufficiently extensive to present severe competition for tree seedlings unless site treatment is prescribed. Opportunities also exist to manage *Populus tremuloides* for a variety of resource values including forage production for livestock.

Other studies.—ABLA/CARO has previously been described by Steele and others (1983) for southeastern Idaho. Their type appears to be similar except for the occurrence of *Pinus contorta* as a seral associate. Mauk and Henderson (1984) do not include ABLA/CARO in their classification for northern Utah, but some sites belonging to their ABLA/BERE and *Abies lasiocarpa/Osmorhiza chilensis* h.t.'s are comparable.

Abies concolor Series

Distribution.—The *Abies concolor* series, a major grouping of h.t.'s within the study area, is especially common on the southern plateaus. Our series includes eight h.t.'s, of which four are major and one incidental. Sites are characteristically cool and dry and are usually on northern exposures. Elevations range from 6,200 to 9,200 feet (1 890 to 2 800 m), with ABCO/QUGA representing the lower extreme and ABCO/BERE or ABCO/SYOR common at the higher altitudes. Several h.t.'s within the series, including ABCO/PHMA, ABCO/CELE, and ABCO/QUGA, represent lower timberline conditions. Other types, such as ABCO/ARPA and ABCO/BERE, are usually above closely related types within the *Pseudotsuga menziesii* series. Higher elevations or more moist conditions may support *Abies lasiocarpa* and belong to that series.

Vegetation.—Sites supporting *Abies concolor* as a climax species are apparently too warm and dry for *Abies lasiocarpa* and *Picea engelmannii*. The most common associates of this series include *Pseudotsuga menziesii* and *Pinus ponderosa*, with *Picea pungens* and *Populus tremuloides* present in the ABCO/BERE and ABCO/JUCO h.t.'s. The characteristically shrubby undergrowths are similar to the *Pseudotsuga menziesii* and portions of the *Pinus ponderosa* and *Abies lasiocarpa* series.

Soils/climates.—Our series shows a strong affinity for limestone and sandstone substrates (appendix F). ABCO/CELE and ABCO/JUCO are the only exceptions and are found most often on andesitic volcanics. This relationship is similar to the *Pseudotsuga menziesii* series. Amounts of bare soil and exposed rock are relatively uniform; only ABCO/ARPA represents sites with an average of more than 20 percent bare soil. Litter accumulations tend to be nonuniform and patchy, with depths ranging from 0.9 to 1.7 inches (2.3 to 4.4 cm) and averaging 1.2 inches (3.2 cm). Surface textures are variable and are best discussed by h.t. Many sites within this series have experienced severe erosion in the past.

Accurate, long-term climatological data for much of this series are lacking. However, analyses from two sites, and general observations and extrapolations, suggest that the series represents environments beyond the drought and temperature tolerances of *Abies lasiocarpa* and *Picea engelmannii* and within the zone of somewhat uniformly distributed annual precipitation. Thus, the series is found at elevations lower than *A. lasiocarpa* and *P. engelmannii* and is confined to the southern and western portion of the study area that receives summer moisture. Mauk and Henderson (1984) suggest that the northern distribution of the series, near Logan, UT, might correspond to a mean January temperature of about 32 °F (0 °C). Mean temperatures below this threshold apparently limit seedling establishment.

Productivity/management.—Our series generally represents sites with only limited opportunities for timber management. Yields are low and many sites are poorly stocked. Where present, *Pseudotsuga menziesii* presents the best opportunity for successful silvicultural manipulation. Low elevation, and especially lower timberline sites, often resemble the adjacent nonforest shrub communities and may have undergrowths of competing shrubs. Because of its proximity to rural communities, most of the series has had a history of selective harvesting.

Knowledge of fire ecology for *Abies concolor* sites is only superficial. Although many of our sample stands have burned as a result of historic logging, the natural fire interval probably is relatively short. *Abies concolor* is not very resistent to fire as a sapling or pole but becomes increasingly more tolerant with age as the thin smooth bark thickens. Low branches also increase its susceptibility. Fires that are carried by undergrowth species, such as *Quercus gambelii, Juniperus communis*, and graminoids, may easily torch-out on young *A. concolor. Pseudotsuga menziesii* and *Pinus ponderosa* may be favored by these fires because of greater fire resistence and the creation of favorable seed beds. Crane (1982) presents preliminary successional trends of *Abies concolor* h.t.'s in Colorado that appear reasonable for most of our types.

Wildlife values of this series are not well documented. Many of our h.t.'s apparently provide cover and browse for deer, presumably during spring and fall. Mauk and Henderson (1984) suggest the preference of *Abies concolor* cambium tissue as food for several rodent species, especially porcupines.

Abies concolor/Physocarpus malvaceus h.t. (ABCO/PHMA; White Fir/Ninebark)

Distribution.—ABCO/PHMA, an incidental h.t. sampled in the Pahvant Mountains, is confined to steep northern slopes immediately above the *Acer glabrum-Quercus gambelii* woodlands. Our sites were all below 7,500 feet (2 290 m) in elevation. Adjacent types are most likely ABCO/BERE, ABCO/ACGL, or undescribed nonforest communities.

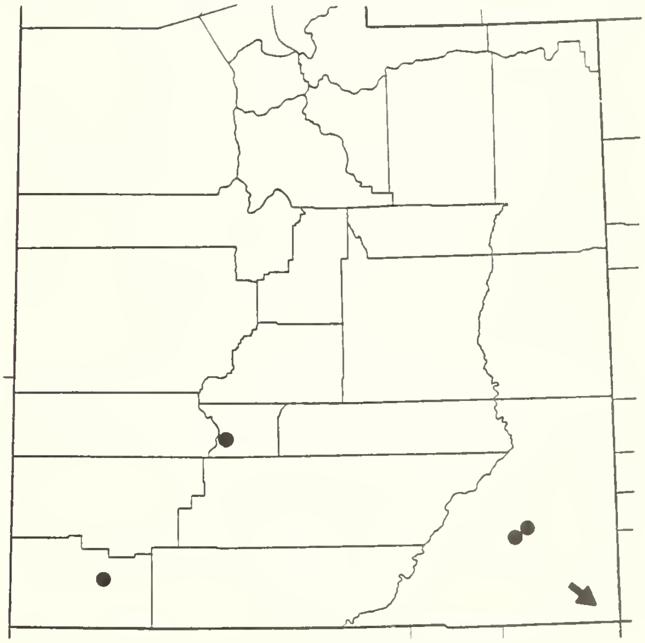
Vegetation.—Both *Abies concolor* and *Pseudotsuga menziesii* codominate in the overstory. The shrubby undergrowth consists of *Physocarpus malvaceus, Quercus gambelii*, and *Amelanchier alnifolia* in a tall shrub stratum, overtopping a lower stratum of *Berberis repens, Pachistima myrsinites*, and *Rosa woodsii*. Herbaceous species include *Carex geyeri, Lathyrus lanszwertii*, and *Lathyrus pauciflorus*.

Soils.—Sampled stands are on limestone and sandstone parent material. Litter accumulations are relatively high. Surface textures are loam and silt loam.

Productivity/management.—Individual trees may have relatively high site index values, but yields are expected to be low to moderate. Steep slopes and intense undergrowth competition may preclude most management alternatives. These sites may have highest value as spring and fall deer habitat. Other management implications should be similar to PSME/PHMA.

Other studies.—The ABCO/PHMA h.t. is similar to that described for the Wasatch and Stansbury Mountains of northern Utah by Mauk and Henderson (1984).

Abies concolor/Acer glabrum h.t. (ABCO/ACGL; White Fir/Mountain Maple)



Distribution.—ABCO/ACGL is a minor h.t. of our study area. Sites belonging to this type were found in the Pine Valley, Abajo, and Tushar Mountains. It represents lower to midslope positions at low elevations within the *Abies concolor* series; our sample sites ranged from 7,400 to 8,400 feet (2 260 to 2 560 m) in elevation. Exposures are northern and topography is usually concave or undulating. Adjacent drier sites usually belong to ABCO/BERE, while more moist sites are stream bottoms.

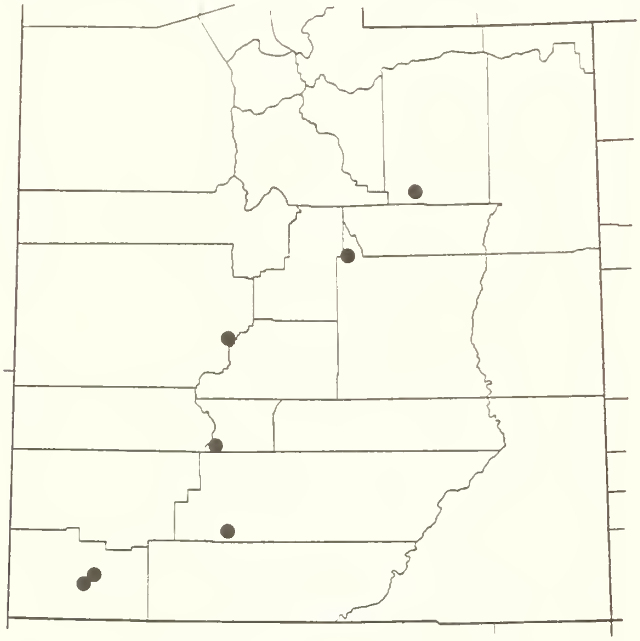
Vegetation.—A dense overstory in mature stands is composed of *Abies concolor*, with *Pseudotsuga menziesii* usually present as a persistent seral associate. *Populus tremuloides* is also an important early seral component. The shrubby undergrowth consists of a distinctly tall stratum, including *Acer glabrum*, *Quercus gambelii*, *Prunus virginiana*, and *Amelanchier alnifolia*, overtopping a low shrub stratum of *Berberis repens*, *Pachistima myrsinites*, *Rosa woodsii*, and *Symphoricarpos oreophilus*. *Bromus ciliatus* and *Carex rossii* are the most common graminoids. A diverse forb component includes *Thalictrum fendleri*, *Smilacina stellata*, and *Erigeron speciosus*.

Soils.—Parent materials are variable, depending upon locale. Our sites include both Tertiary sandstone and andesitic volcanics. Surface textures are mostly loam. Most of our sites contain relatively high amounts of exposed rock.

Productivity/management.—Yields and management appear similar to ABLA/ACGL.

Other studies.—Mauk and Henderson (1984) suggest that ABCO/ACGL may exist in the Wasatch Mountains near Salt Lake City. DeVelice and others (in press), and Moir and Ludwig (1979) describe similar conditions in southwestern Colorado and northern New Mexico.

Abies concolor/Cercocarpus ledifolius h.t. (ABCO/CELE; White Fir/Curlleaf Mountain-Mahagany)



Distribution.—ABCO/CELE, a minor h.t. of the *Abies concolor* series, is found sporadically throughout the lower elevations in the western part of the study area. It also occurs on the Wasatch and Tavaputs Plateaus. It may be most common in the Pine Valley Mountains in southwestern Utah. Our sites range in elevation from 7,000 to 9,400 feet (2 130 to 2 860 m) and are usually on gentle to steep straight or convex slopes with northern exposures. Adjacent sites usually support nonforest communities of *Quercus-Cercocarpus* woodlands, or on more moist sites, the ABCO/BERE h.t.

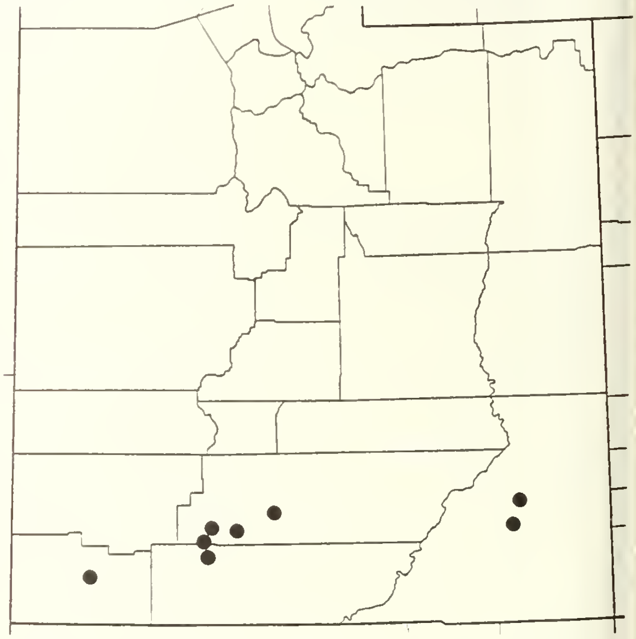
Vegetation.—Although *Abies concolor* is the indicated climax tree, mature stands of *A. concolor* are rarely found. Usually *Pseudotsuga menziesii* and *Pinus ponderosa* dominate these sites. *Pinus flexilis* and *Juniperus scopulorum* are often present in small amounts. The shrub-dominated undergrowth may become dense, with *Cercocarpus ledifolius*, *Quercus gambelii*, *Amelanchier alnifolia*, *Berberis repens*, and *Symphoricarpos oreophilus* usually present. *Carex rossii* and *Poa fendleriana* are the most characteristic graminoids. Forbs are negligible.

Soils.—Although a variety of sedimentary and igneous parent materials are represented, andesitic volcanics are the most common. Many sites have high amounts of exposed rock and bare soil. Patchy litter accumulations averaged only 1.1 inches (2.6 cm). Surface textures are predominantly loam and silt loam.

Productivity/management.—Limited timber data indicate potential yields are very low (appendix D), and represent the poorest sites of the series. Rocky sites and low stocking will reduce expected yields. These sites may function best as spring and fall range for big game, especially deer.

Other studies.—No other studies have described this h.t.

Abies concolor/Arctostaphylos patula h.t. (ABCO/ARPA; White Fir/Greenleaf Manzanita)



Distribution.—ABCO/ARPA is a major h.t. of the *Abies concolor* series in the southern portion of the study area. It usually occurs on relatively gentle benches with undulating topography at midslope positions. A variety of exposures are represented. Elevations range from 8,100 to 8,500 feet (2 470 to 2 590 m). ABCO/ARCA is usually found adjacent to the drier PIPO/ARPA, while more moist conditions are represented by ABCO/BERE, ABCO/SYOR, or PIPU/JUCO.

Vegetation.—*Abies concolor* is the indicated climax tree, but many sites may have open, uneven-aged overstories dominated by mature *Pseudotsuga menziesii* or *Pinus ponderosa* (fig. 8). *Abies concolor* should be present in the understory and will gradually increase. *Juniperus scopulorum* may persist on these dry sites, while *Pinus flexilis* is a long-lived seral associate. The undergrowth consists of dense patches of shrubs, characterized by the diagnostic *Arctostaphylos patula*, along with *Symphoricarpos oreophilus*, *Juniperus communis*, and *Berberis repens*. Graminoids and forbs are usually negligible.

Soils.—ABCO/ARPA shows a strong affinity for limestone substrates, commonly occurring in our study on the Wasatch Formation (appendix F). Although exposed rock is usually less than 10 percent, amounts of bare soil may range up to 80 percent and average 21 percent. Consequently, litter accumulations are patchy and average only 1.1 inches (2.5 cm). Many sites contain evidence of erosion. Surface textures are predominantly loam and silt loam (appendix G).

Productivity/management.—Timber potentials are generally very low (appendixes D and E). Stocking limitations, droughty soils, and low site indexes will reduce expected yields. Individual trees grow slowly, with most sample stands exceeding 200 years. Attempts to manipulate the overstory in even-aged management may fail. Wildlife may use these sites for browse. Domestic livestock will find little forage.

Other studies.—No other studies have described this h.t.

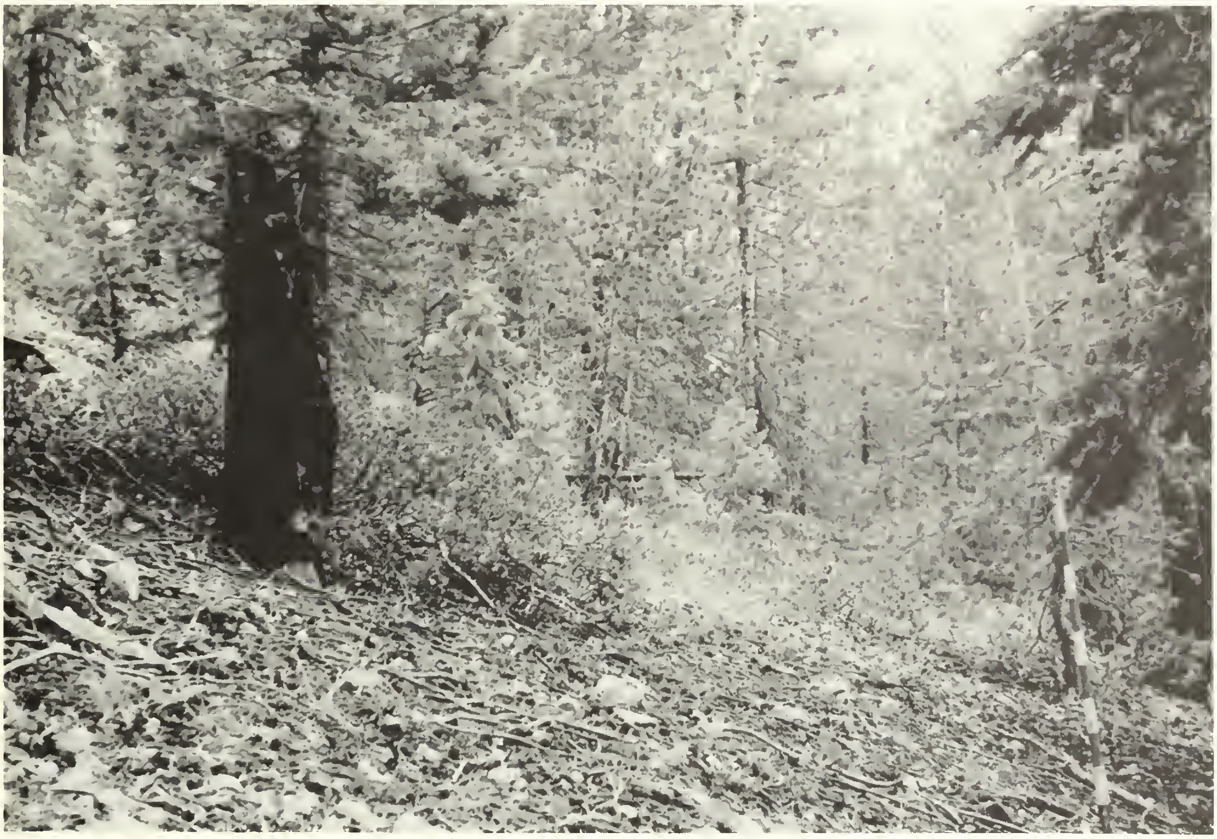
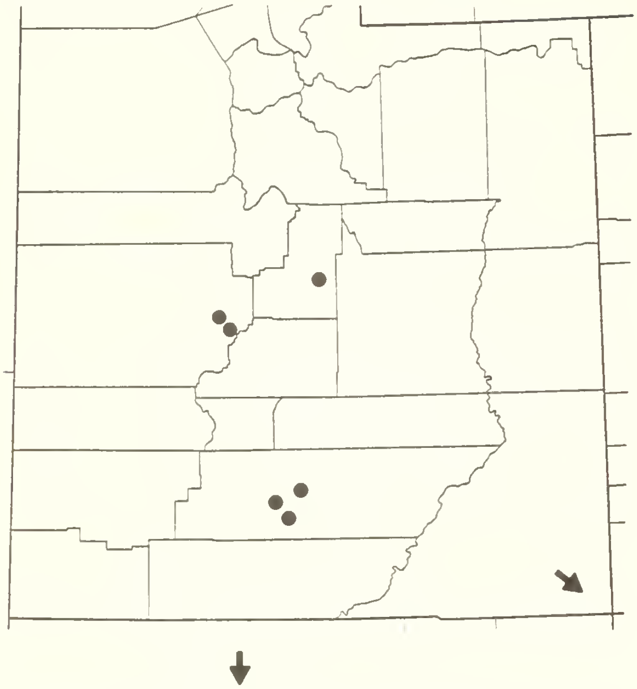


Figure 8.—*Abies concolor/Arctostaphylos patula* h.t. on a steep southwest slope (8,580 feet, 2 610 m) in the East Fork Creek drainage on the Paunsaugunt Plateau. *Abies concolor* is scattered throughout the overstory, which also contains *Pinus ponderosa* and *Pseudotsuga menziesii*. Large patches of *Arctostaphylos patula* are common in the undergrowth.

Abies concolor/Quercus gambelii h.t. (ABCO/QUGA; White Fir/Gambel Oak)



Distribution.—ABCO/QUGA is a minor h.t. of the *Abies concolor* series and occurs primarily in the Pahvant Mountains and on the southern edge of the Aquarius Plateau. It also apparently extends southward into Kane County in Zion National Park. It was found on all but southern and southwestern exposures and ranged from 6,200 to 8,600 feet (1 890 to 2 620 m) in elevation. Our sites usually represent middle to lower slope positions, with straight slopes that are moderate to steep. ABCO/QUGA is usually adjacent to relatively high elevation PIPO/QUGA-SYOR in the Aquarius Plateau. In the Pahvant Mountains, it may be adjacent to *Quercus-Acer grandidentatum* woodlands, and thus represents the lower timberline zone of conifer forests. In both areas, ABCO/BERE may be found on cooler exposures and elevations.

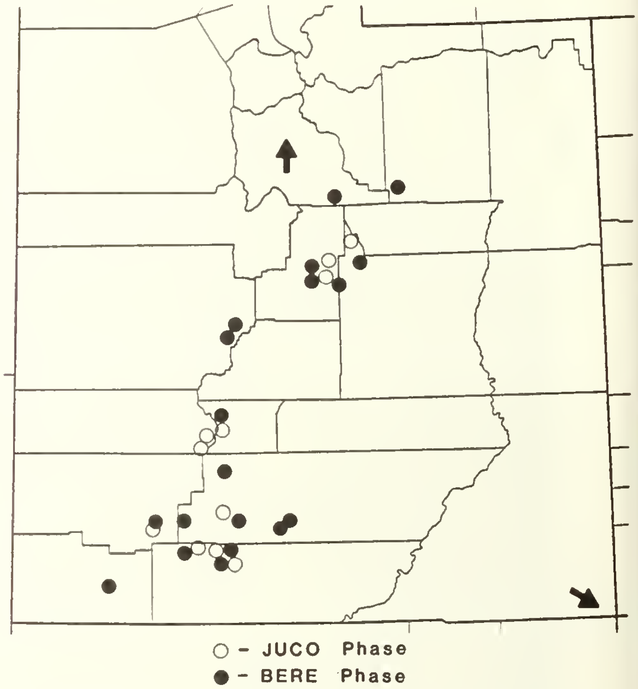
Vegetation.—*Abies concolor* is the indicated climax tree, although it may be poorly represented in many stands dominated by mature *Pseudotsuga menziesii* or *Pinus ponderosa*. *Juniperus scopulorum* is usually present in small amounts. *Populus tremuloides* is noticeably absent. The shrubby undergrowth is dominated by *Quercus gambelii* and *Amelanchier alnifolia*, which may overtop *Berberis repens*, *Pachistima myrsinites*, *Purshia tridentata*, *Rosa woodsii*, and *Symphoricarpos oreophilus*. A light and diverse herbaceous stratum includes *Carex rossii*, *Poa fendleriana*, *Sitanion hystrix*, *Eriogonum racemosa*, and sometimes *Balsamorhiza sagittata*.

Soils.—Parent materials are variable, depending upon locale. Sedimentary, metamorphic, and igneous types are represented (appendix F). Exposed rock and bare soil were present in all sample stands but averaged only 7 and 2 percent, respectively. Litter accumulations averaged 1.7 inches (4.4 cm). Surface textures are variable and range from loam to silt loam to clay loam.

Productivity/management.—Timber potentials range from very low to low (appendixes D and E). Limited data suggest that management should favor *Pseudotsuga menziesii* rather than *Pinus ponderosa* for maximum production. Other features may be similar to PSME/QUGA or ABCO/CELE.

Other studies.—Somewhat similar conditions apparently exist in New Mexico and Arizona and have been described as the *Abies concolor-Pseudotsuga menziesii/Quercus gambelii* h.t. by Moir and Ludwig (1979) and the ABCO/QUGA h.t. by DeVelice and others (in press).

Abies concolor/Berberis repens h.t. (ABCO/BERE; White Fir/Oregon Grape)



Distribution.—ABCO/BERE is a major h.t. of the *Abies concolor* series. Sample stands are distributed throughout the study area except for the easternmost LaSal and Abajo Mountains. Two phases are recognized, with slight differences in environmental site characteristics and management opportunities. In general the h.t. can be found between 7,300 and 9,600 feet (2 230 to 2 930 m) in elevation on a variety of exposures. The type usually represents relatively cool and dry midslope positions on gentle to steep slopes. Adjacent, colder sites, often at higher elevations, belong to the ABLA/BERE, PIPU/BERE, or ABCO/SYOR h.t.'s. Warmer sites may belong to a variety of different h.t.'s, including PSME/BERE, ABCO/ARPA, PIPO/SYOR, and sometimes PSME/SYOR, although parent material differences exist between some of these types. In the northern and western portion of the study area, ABCO/BERE may represent the lowest elevation coniferous timber sites, with nonforest communities dominated by *Populus tremuloides* or *Quercus* and *Acer* immediately adjacent.

Vegetation.—Old-growth stands are usually unevenaged and contain a variety of species in the overstory.

Pure *Abies concolor* stands are rare. *Pseudotsuga menziesii* and *Populus tremuloides* are the most common seral associates. In some areas, *Pinus ponderosa* may persist; it usually represents the drier extreme of the h.t. Undergrowth vegetation is characterized by a sparse layer of low shrubs, including *Berberis repens, Symphoricarpos oreophilus, Pachistima myrsinites*, and *Rosa woodsii*. Other features are distinguished by phase.

Juniperus communis (JUCO) phase: The dry extreme of the h.t. is represented by the JUCO phase, which is distributed throughout the study area. It usually occurs on middle to lower slopes and benches with predominantly southwest and northeast exposures. The overstory may include *Picea pungens* or *Pinus flexilis* in addition to the other seral species. Phasal difference is based upon the presence of *Juniperus communis*, which may have relatively high coverage in large patches (fig. 9). Forbs and graminoids are negligible.

Berberis repens (BERE) phase: Sites lacking abundant *Juniperus communis* belong to the BERE phase, which may represent slightly more moist conditions. It most commonly occurs on straight slopes above 8,000 feet (2 440 m) with northern or northeastern exposures. *Amelanchier alnifolia*, in addition to species listed for the h.t., create the shrub component. The BERE phase also contains more forbs than the JUCO phase, with *Geranium viscosissimum, Lathyrus lanszwertii*, and *Thalictrum fendleri* notable examples.

Soils.—Soils within the ABCO/BERE h.t. are usually derived from limestone or dolomite (appendix F) that has weathered in place or has been transported by colluvial action. A few sites within the JUCO phase also contain evidence of alluvial deposition. Cretaceous and Tertiary sandstones and andesitic parent materials are also represented. Soils are usually rocky and gravelly, with bare soil ranging as high as 30 percent in the JUCO phase. Accumulations of litter average 0.9 inch (2.3 cm) in the JUCO phase and 1.5 inches (3.9 cm) for the BERE phase. Surface textures show little difference by phase and range from loam to silt loam and clay loam (appendix G). Many of our sample sites have had serious gully and sheet erosion.

Productivity/management.—Timber yields are generally very low to low for the h.t. (appendixes D and E). The BERE phase may contain sites of higher productivity, presumably due to a more protected exposure. *Pseudotsuga menziesii* presents the best opportunity for management if silvicultural prescriptions are carefully developed. Many of the sites, especially at the lower elevations, contain evidence of past fire and cutting. This is assumed to be the result of early settlers seeking house logs and building products (refer to discussion of

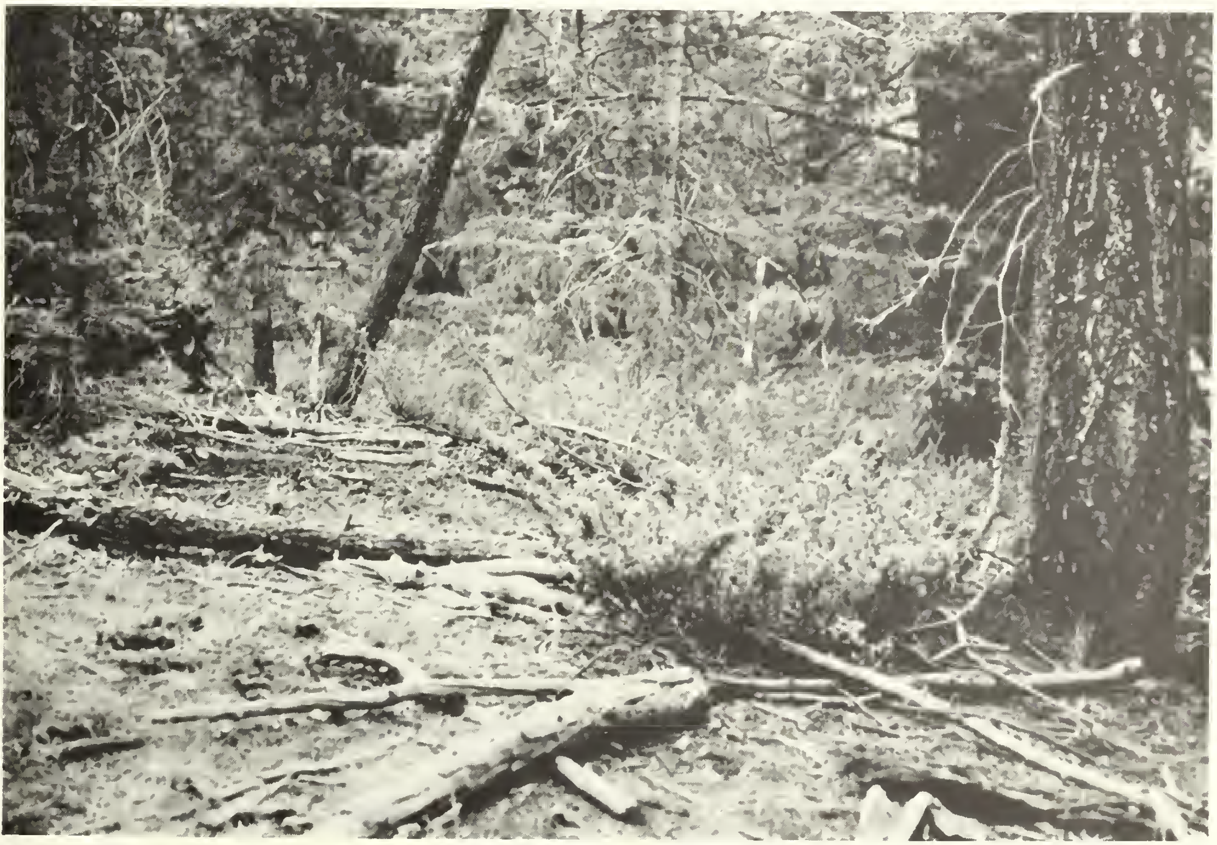
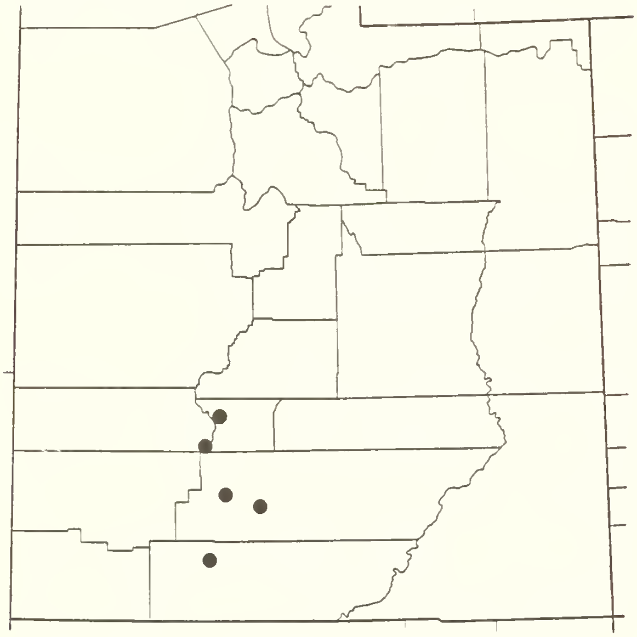


Figure 9.—*Abies concolor/Berberis repens* h.t., *Juniperus communis* phase on a gentle northern slope (8,160 feet, 2 490 m) in Bryce Canyon National Park. Old-growth *Pinus ponderosa* and *Pseudotsuga menziesii* dominate the overstory, with *Abies concolor* throughout the understory. Large clumps of *Juniperus communis* are conspicuous. Other shrubs include *Berberis repens* and *Symphoricarpos oreophilus*.

logging history preceding h.t. descriptions). Recovery from both fire and selective logging (high-grading) has been slow. Dwarf mistletoe (*Arceuthobium douglasii*) may be common on *Pseudotsuga menziesii*. Big game, especially deer, apparently make heavy use of those sites, presumably during spring and fall.

Other studies.—Pfister (1972) first noted the presence of *Abies concolor* with undergrowth similar to the ABLA/BERE h.t. Our BERE phase extends into northern Utah where Mauk and Henderson (1984) describe it and another phase that resembles our ABCO/QUGA, ABCO/CELE, and ABCO/SYOR h.t.'s. Similar conditions exist south of our study area and have been described as the *Abies concolor-Pseudotsuga menziesii* h.t., *Berberis repens* phase in the San Juan Mountains (Moir and Ludwig 1979).

Abies concolor/Juniperus communis h.t. (ABCO/JUCO; White Fir/Common Juniper)



Distribution.—ABCO/JUCO is a minor h.t. in the Sevier and Paunsaugunt Plateaus, Escalante, and Tushar Mountains. It usually is found on gentle to steep northern slopes between 7,900 and 9,000 feet (2 410 and 2 740 m) in elevation. Adjacent, more moist sites may belong to ABCO/BERE, while drier sites are often ABCO/ARPA.

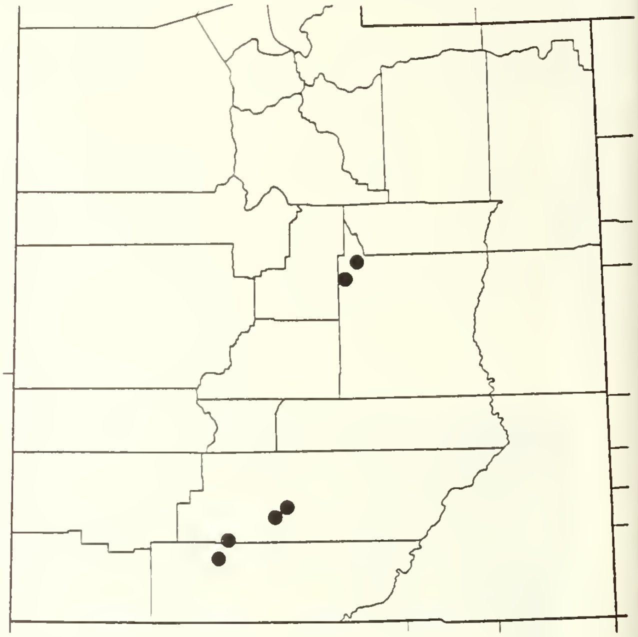
Vegetation.—*Abies concolor* is the indicated climax tree and usually dominates mature stands. *Pseudotsuga menziesii, Picea pungens, Pinus flexilis*, and *Populus tremuloides* are seral associates. The undergrowth is characterized by an easily noticeable and clumpy stratum of *Juniperus communis*. Other common shrubs include *Symphoricarpos oreophilus, Rosa woodsii, Ribes cereum*, and *Berberis repens*. The herbaceous stratum is usually depauperate; only *Carex rossii* has high constancy.

Soils.—Our sites contain gravelly soils derived from limestone and andesite and basaltic volcanic parent materials, with colluvial and residual depositional actions. Other features are similar to the series description.

Productivity/management.—Limited data suggest timber potentials are low because of low stocking levels and site index. In general, management options resemble those of low elevation sites within the ABLA/JUCO h.t.

Other studies.—No other studies have identified this h.t.

Abies concolor/Symphoricarpos oreophilus h.t. (ABCO/SYOR; White Fir/Snowberry)



Distribution.—ABCO/SYOR is a major h.t. of the *Abies concolor* series and is found primarily on the southern half of the Aquarius and Paunsaugunt Plateaus. It also occurs sporadically across the Wasatch Plateau. Typically, sites are midslope on moderate to steep northern slopes between 8,400 and 9,300 feet (2 560 and 2 830 m) in elevation. One site on the Wasatch Plateau was as low as 6,800 feet (2 070 m). ABCO/SYOR represents cool and dry conditions that are generally above the ABCO/JUCO and ABCO/BERE h.t.'s. More moist sites may be lower elevations of extremes within the ABLA/BERE or ABLA/JUCO h.t.'s.

Vegetation.—Mature stands are usually dominated by either *Pseudotsuga menziesii* or *Pinus ponderosa*, with only scattered *Abies concolor*. A light shrub canopy dominates the undergrowth (fig. 10) and contains *Symphoricarpos oreophilus, Rosa woodsii, Amelanchier alnifolia*, and occasionally trace amounts of *Berberis repens, Ribes cereum*, and *Quercus gambelii*. *Carex rossii* and *Poa fendleriana* are common graminoids. Forbs are noticeably sparse.

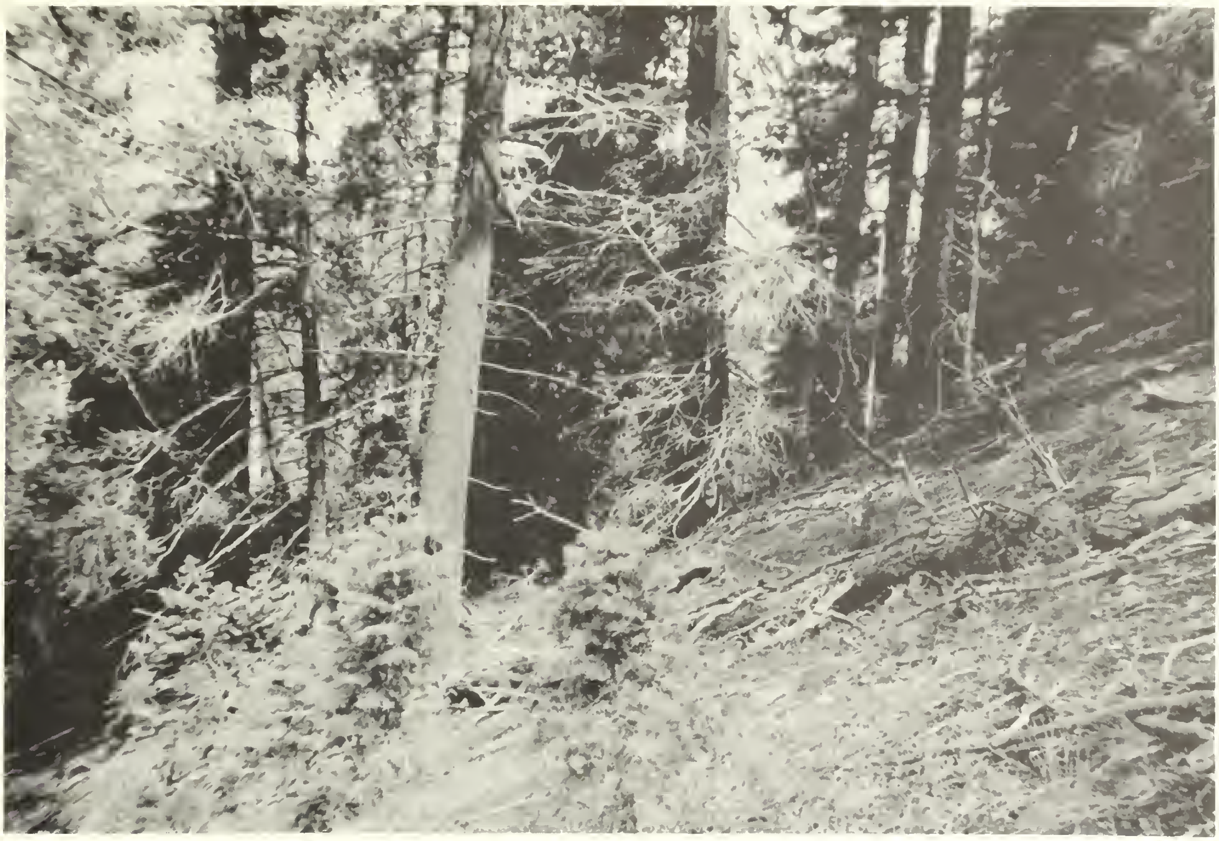


Figure 10.—*Abies concolor/Symphoricarpos oreophilus* h.t. on a steep western slope (8,400 feet, 2 560 m) just above the East Fork Creek on the Paunsaugunt Plateau. The overstory canopy is comprised of *Abies concolor, Pseudotsuga menziesii*, and scattered *Pinus ponderosa*. A depauperate undergrowth contains *Symphoricarpos oreophilus, Poa fendleriana*, and *Bromus ciliatus*.

Soils.—Our sample sites are on predominantly lime-one or Tertiary sandstone (appendix F) that has either eathered in place or been modified by colluvial action. are soil and exposed rock are usually negligible, though a few sites contain as much as 20 percent. itter accumulations average 1 inch (2.5 cm). Soils sually contain little gravel, although textures are edominantly sandy loam and loam (appendix G). As ith ABCO/BERE, many sample sites have experienced eet erosion.

Productivity/management.—Timber potentials are sually very low (appendix D). Because of proximity to rly settlements, many stands show evidence of previs selective harvesting (high-grading). As with BCO/BERE, fires have been frequent, although this pe lacks the continuous ground fuels to burn under ost normal conditions. Dwarf mistletoe (*Arceuthobium uglasii*) is relatively severe on *Pseudotsuga menziesii* roughout this type. Wildlife features are similar to the ABCO/BERE h.t.

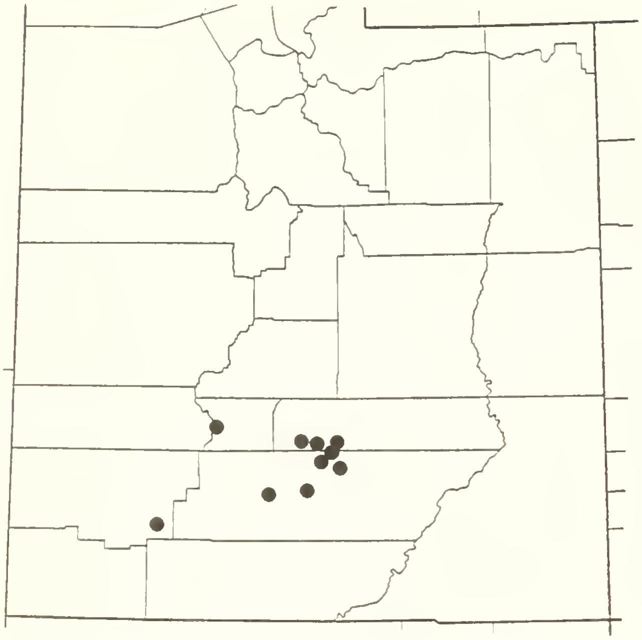
Other studies.—No other studies have described this h.t.

Picea engelmannii Series

A single h.t., PIEN/RIMO, belongs to our *Picea engelmannii* series. Although *Picea engelmannii* is often an important seral or even codominant associate in many of the *Abies lasiocarpa* and *Abies concolor* h.t.'s, interpretations of successional trends indicate that only in the absence of *Abies* is *P. engelmannii* technically climax. This rather narrow concept allows greater accuracy for the user. All sites potentially capable of supporting *A. lasiocarpa* or *A. concolor* are keyed elsewhere, and the *Picea engelmannii* series is left relatively pure.

The series description follows that of the PIEN/RIMO h.t.

Picea engelmannii/Ribes montigenum h.t. (PIEN/RIMO; Engelmann Spruce/Mountain Gooseberry)



Distribution.—PIEN/RIMO is a major h.t. in the southern portion of the study area, occurring on the Aquarius and Markagunt Plateaus and throughout the Boulder, Escalante, and Tushar Mountains. It normally represents the coldest, highest elevation sites within the closed forests; it may grade into krummholz with increased stress from wind shear and winter desiccation. Warmer sites usually belong to the ABLA/RIMO h.t. PIEN/RIMO can be found on all aspects, but northern exposures are most common. Topography is usually moderate to steep, middle to upper slopes and benches, with elevations ranging from 10,000 to 11,440 feet (3 050 to 3 490 m).

Vegetation.—Stands may be solid and continuous, or patchy, with intermingled forb meadows. *Picea engelmannii* is normally the only conifer present on sites and often layers in addition to regenerating by seed. The presence of *Abies lasiocarpa* is accidental or may mark the ecotone to the warmer ABLA/RIMO h.t. *Populus tremuloides* is occasionally present as a minor seral component; however, successional rates presumably are relatively rapid. The depauperate undergrowth (fig. 11) is characterized by scattered *Ribes montigenum*, often found at or near the base of *P. engelmannii*, where snow tends to melt first. *Carex rossii*, *Festuca ovina*, and sometimes *Trisetum spicatum* are present in small amounts. Characteristic forbs include *Achillea millefolium*, *Aquilegia coerulea*, *Astragalus miser*, and

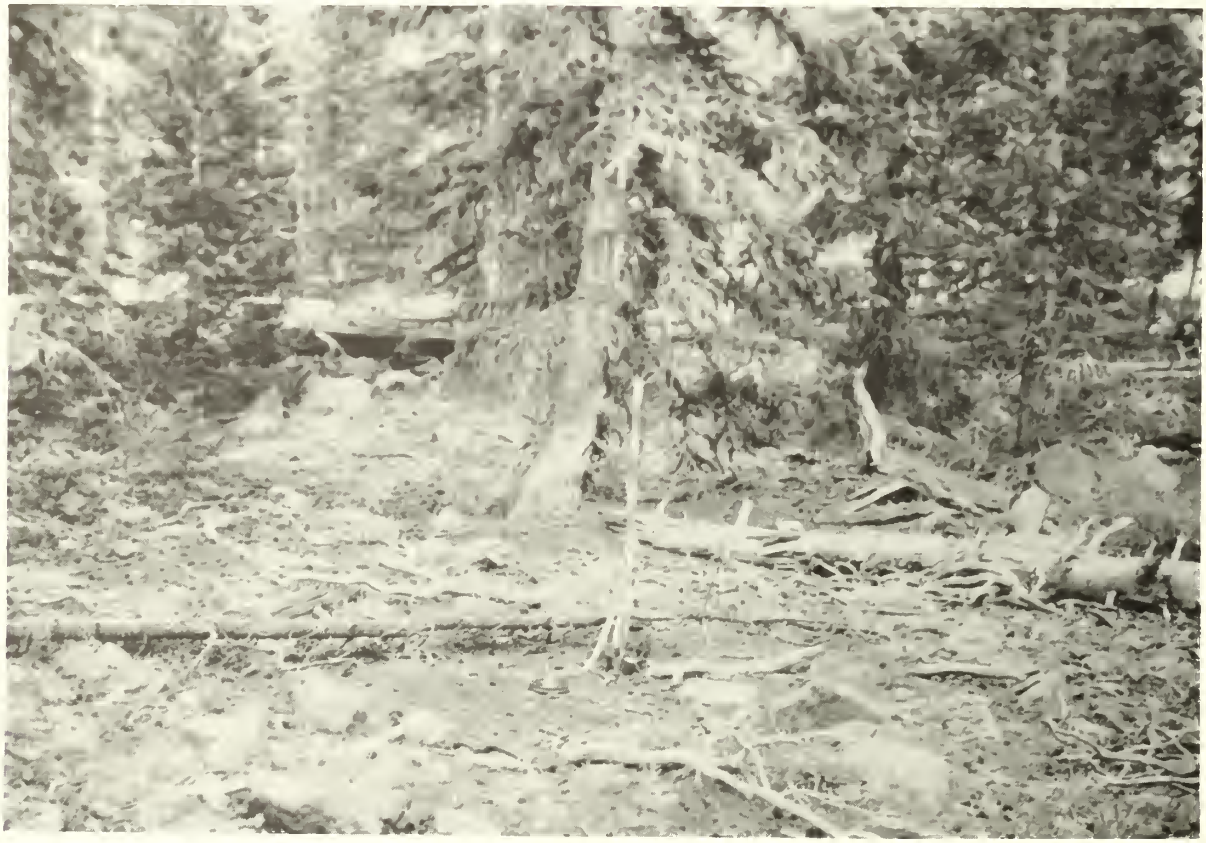


Figure 11.—*Picea engelmannii/Ribes montigenum* h.t. on a gentle southeastern slope (11,080 feet, 3 380 m) in the Boulder Mountains near Meeks Lake. *Picea engelmannii* is the only tree on the site. *Ribes montigenum* and *Carex rossii* characterize the depauperate undergrowth.

Polemonium pulcherrimum. Lupinus argenteus may occur in small patches where overstory canopy openings permit more sunlight.

Soils/climate.—PIEN/RIMO soils are almost exclusively derived from weathered andesitic flows (appendix F). Most sites, especially those in the Boulder Mountains, have relatively high amounts of rock exposed at the surface. Bare soil ranges from none to 60 percent. Litter depth is relatively constant in sites having little disturbance and averages 1 inch (2.5 cm). Surface textures range from sandy loam to clay loam, but loam and silt loam are most common (appendix G). Climatological data for the type are represented by the Blowhard Radar Station (appendix H). Although ambient air temperatures displayed are reasonable, this site receives extensive winds that may reduce snowpack accumulations representative of the complete range of the h.t. (Arlo Richardson, retired Utah State Climatologist, pers. comm.). It probably provides a characteristic example of *Picea engelmannii* krummholz.

Productivity/management.—Timber potentials are low to moderate (appendixes D and E). The low site index for *Picea engelmannii*, short growing seasons, and rocky soils combine to reduce yields. Under the best conditions at lower elevations, small openings that maintain the site protection from wind and high insolation may respond favorably. Careful consideration should be given the prevailing wind patterns and wind firmness of the existing stand before creating openings. Mielke (1950) and Schmid and Hinds (1974) discuss the severe overstory die-off of *P. engelmannii* resulting from bark beetle (*Dendroctonus rufipennis* [Kirby]; = *D. engelmannii* [Hopkins]) infestations in the Boulder Mountains, from 1916 to 1929. Schmid and Frye (1977) relate outbreaks of the beetle to a variety of factors, including blowdown and fuels accumulation. Periodic infestation has most likely helped create the existing all-age structure. Silvicultural prescriptions should be designed to eliminate quantities of slash that encourage beetle population buildups, but also to retain slash for amelioration of site conditions following overstory removal. Also likely to affect management of *P. engelmannii* is the presence of shoestring root rot, *Armillaria mellea*. Big game, especially deer and elk, may use the PIEN/RIMO h.t. for summer and fall hiding and thermal cover, moving out into adjacent meadows for forage. Canopy removal, by cutting or natural processes, may increase undergrowth forage slightly. On most sites, because of the late snowmelt, watershed protection will be the highest management emphasis.

Other studies.—Similar conditions have been described from the Wind River and Owl Creek Mountains in Wyoming, although these sites also support *Pinus contorta* and *Pinus albicaulis* (Steele and others 1983). In Utah, PIEN/RIMO was first described by Pfister (1972) from the Boulder Mountains. This treatment maintains the previous concept and extends the distribution to other high elevation plateaus.

Picea pungens Series

Distribution.—Stands containing *Picea pungens* as a component occur throughout the study area, with the exception of the LaSal, Abajo, and Pine Valley Mountains. *Picea pungens* becomes increasingly more important in central and southern Colorado (Eyre 1980). Its absence in the LaSal and Abajo Mountains may partially be the result of bedrock; these areas contain more igneous parent material within the elevational zone in which *P. pungens* might survive.

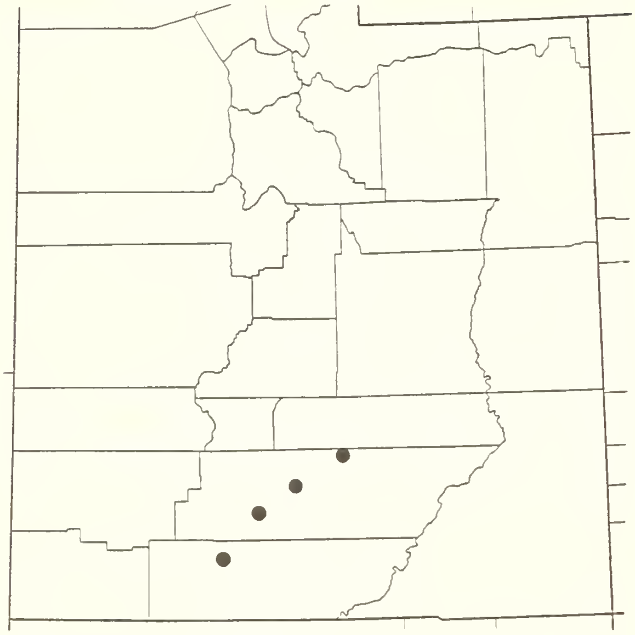
Picea pungens is a climax dominant in only three h.t.'s. The series is somewhat unique in that it contains moist sites (PIPU/EQAR) and relatively dry sites (PIPU/BERE and PIPU/JUCO) but lacks the full spectrum of mesic sites. Elevational ranges are best presented by h.t. but extend from 7,600 to 9,000 feet (2 320 to 2 740 m). Sites are normally on gentle slopes and benches or alluvial terraces, usually associated with cold air accumulation. Ecotones with adjacent types vary by h.t.

Vegetation.—Although *Picea pungens* is the climax tree, many other species are common associates. *Picea engelmannii* is also occasionally considered climax within this series when it occurs within the PIPU/EQAR h.t. Most important seral associates of the series include *Pseudotsuga menziesii*, *Populus tremuloides*, and *Pinus ponderosa*. *Picea pungens* is more intolerant than *Abies lasiocarpa*, *Abies concolor*, and *P. engelmannii*. It produces moderate to heavy cone crops in most years and thus may be relatively sensitive in its seedbed requirements (Jones 1974). Cones are often cached in large middens by the red squirrel (*Tamiasciurus hudsonicus*) in cool, moist sites (Finley 1969). These sites may belong to either the PIPU/JUCO or PIPU/EQAR h.t.'s. The undergrowth within the series varies by h.t. and is characteristically forby in PIPU/EQAR, shrubby in PIPU/JUCO, and almost depauperate in PIPU/BERE.

Soils/climate.—Alluvial, fluvial, and colluvial depositions are all represented within the series. Nonigneous parent material is more common but not exclusive (appendix F). Climatic data are not available for this rather narrow series.

Productivity/management.—Timber values are best on the most moderate portions of PIPU/BERE, but limited opportunities also exist within the PIPU/JUCO h.t. *Pinus ponderosa*, if present, presents the most opportunities for management. Otherwise, *Pseudotsuga menziesii*, *Picea pungens*, and even *Populus tremuloides* may be considered, depending upon h.t. Watershed protection constraints in the PIPU/EQAR h.t. will usually outweigh other resource values.

Picea pungens/Equisetum arvense h.t. (PIPU/EQAR; Blue Spruce/Common Horsetail)



Distribution.—PIPU/EQAR is a minor h.t. that occurs in the southern portion of the study area, including the Aquarius and Paunsaugunt Plateau. It ranges in elevation from 8,000 to 9,000 feet (2 440 to 2 740 m) and is restricted to gentle lower subirrigated slopes and benches or terraces adjacent to streams. It most commonly occurs on northwest to northeast aspects, but probably is more significantly influenced by edaphic relationships. Surface topography is usually hummocky. Adjacent drier sites are strongly contrasting and usually belong to PIPU/JUCO, PSME/SYOR, PSME/BERE, ABLA/RIMO, ABLA/BERE, ABLA/JUCO, or ABLA/CARO. More moist sites usually support riparian communities such as those dominated by *Populus angustifolia*.

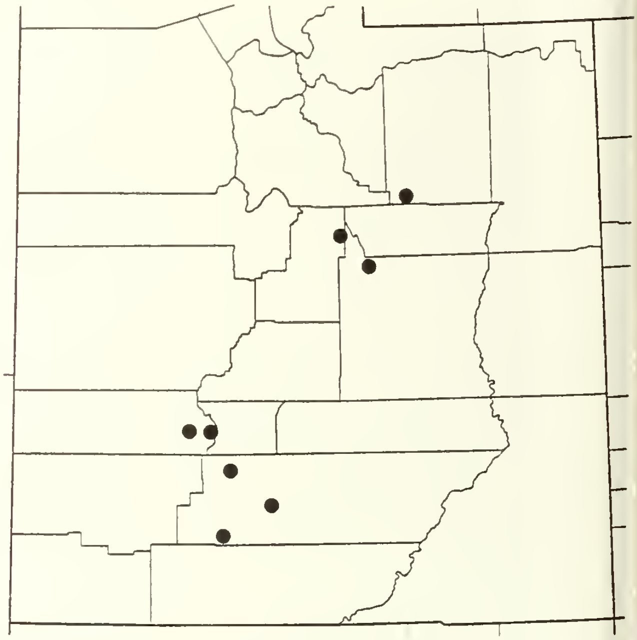
Vegetation.—*Picea pungens* dominates the site. On well-drained extremes of this type, *Populus tremuloides* may persist as a seral component. *Pseudotsuga menziesii, Abies lasiocarpa*, or *Picea engelmannii* may also occur infrequently; their presence is usually associated with raised microsites created by root crown hummocks and windthrow mounds. The dense undergrowth is dominated by forbs and graminoids. Coverage of *Equisetum arvense, Geranium richardsonii, Smilacina stellata, Osmorhiza chilensis*, and *Thalictrum fendleri* is abundant. Common graminoids include *Carex disperma* and *Glyceria elata*. At the wet extreme of this type, undisturbed sites may be dominated by a single species such as *Equisetum, Carex*, or *Glyceria*. Increased disturbance usually results in higher diversity of associated forbs. A light shrub layer may sometimes exist consisting of *Lonicera involucrata, Rosa woodsii*, or *Symphoricarpos oreophilus*, usually on raised hummocks.

Soils.—Parent materials usually consist of basalt or Cretaceous sandstone. Soils show strong influence of fluvial deposition and lack coarse fragments. Textures are silt loam to clay loam. Most sites have a thick accumulation of litter and partially decomposed organic matter; this averages 5.6 inches (14.4 cm). Ground-disturbing activities can often churn this into muck because of the high water tables. Bare soil and exposed rock are negligible.

Productivity/management.—Timber potentials are moderate, but site instability presents major considerations for any attempts in overstory removal. Even small group or single-tree selection systems, with activity contained to when soils are frozen, will result in a raised water table and possible soil loss. *Picea*, growing under these moist conditions, is also extremely susceptible to windthrow. Big game, especially black bear and elk, may make seasonal use of these sites.

Other studies.—PIPU/EQAR is similar to conditions in western Wyoming and central Idaho described by Steele and others (1983) and Steele and others (1981), except *Picea pungens* is replaced by *Picea engelmannii*. These researchers distinguished two different h.t.'s based upon the presence of *Equisetum arvense* and *Carex disperma*. The PIEN/EQAR h.t. is also found in northern Utah, where it includes *P. pungens* (Mauk and Henderson 1984). This treatment combines *Equisetum arvense* and *Carex disperma* for southern Utah because of their ecological similarities in site and the similarities in management.

Picea pungens/Juniperus communis h.t. (PIPU/JUCO; Blue Spruce/Common Juniper)



Distribution.—PIPU/JUCO, a major h.t. within the central portion of the study area, occupies middle to lower slopes, benches, and stream bottoms where cold air accumulates. It occurs on a variety of aspects and elevations, but northwest to northeast at 8,000 to 8,600 feet (2 440 to 2 620 m) are most common. Ecotones with adjacent types are relatively sharp and distinct; more moist sites may belong to PIPU/EQAR or undescribed riparian types, while warmer sites usually belong to PIPU/BERE or PSME/BERE.

Vegetation.—*Picea pungens* is the dominant conifer in seral and relatively open, mature stands. *Pinus ponderosa, Pseudotsuga menziesii, Pinus flexilis, Juniperus scopulorum*, and *Populus tremuloides* may all be present as seral associates. The undergrowth is dominated by a low, light shrub canopy consisting of *Juniperus communis, Arctostaphylos uva-ursi, Symphoricarpos oreophilus, Rosa woodsii, Pachistima myrsinites*, and *Berberis repens* (fig. 12). The herbaceous stratum is usually depauperate and may include *Carex rossii, Achillea millefolium, Geranium viscosissimum*, and *Thalictrum fendleri* in trace amounts.

Soils.—Most sites are in alluvium or colluvium derived from limestone, dolomite, or Cretaceous sandstone (appendix F). About half the samples had some gravel in the subsurface. Exposed rock at the surface is negligible; however, bare soil ranges from none to 60 percent. undisturbed sites have litter accumulations of about 1.2 inches (3 cm). Surface textures range from sandy loam to clay loam (appendix G).

Productivity/management.—Timber potentials are very low (appendix D), and management opportunities are dependent upon the presence of the associated species. In the warm extremes of this type, *Pinus ponderosa* may be favored by light shelterwood systems. *Pseudotsuga* and *Picea pungens* may also respond to shelterwood methods. Careful consideration needs to be given to the potential for increasing the effects of cold air drainage and frost pockets.

Other studies.—No other studies have described the PIPU/JUCO h.t., although it appears to have a weak affinity with the *Picea pungens-Pseudotsuga menziesii* h.t., *Juniperus communis* phase described for the Sangre de Cristo and San Juan Mountains in Colorado and New Mexico (Moir and Ludwig 1979). Portions of the PIPU/BERE h.t. described by Kerr and Henderson (1979) are contained within this type.

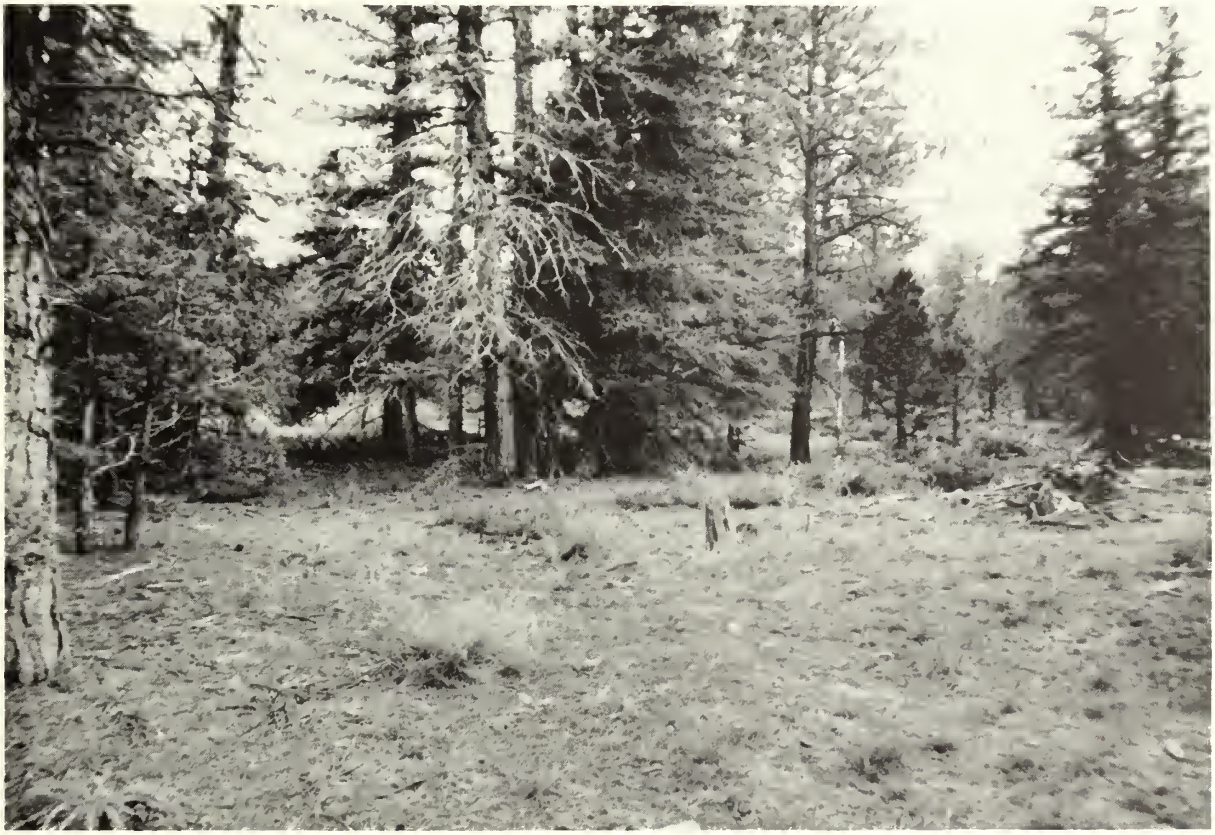
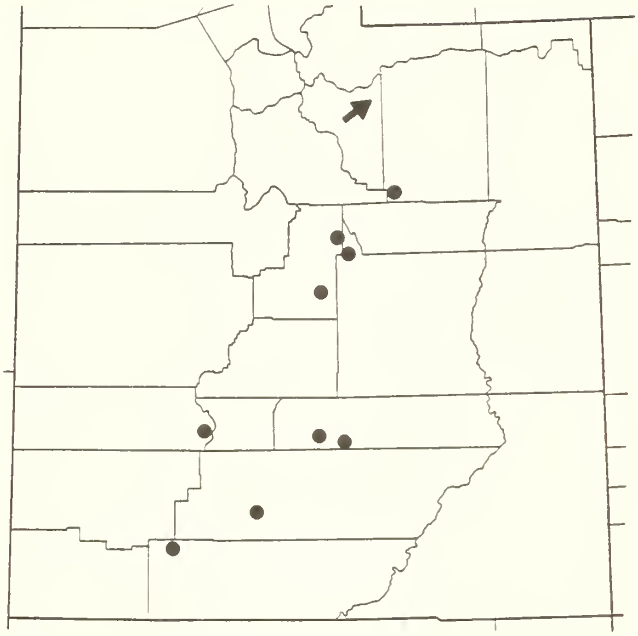


Figure 12.—*Picea pungens/Juniperus communis* h.t. on a gentle northern slope (8,130 feet, 2 480 m) north of Pine Lake in the Escalante Mountains. *Picea pungens* and scattered *Pinus ponderosa* and *Juniperus scopulorum* create a broken canopy. *Juniperus communis* clumps are conspicuous in the undergrowth.

Picea pungens/Berberis repens h.t. (PIPU/BERE; Blue Spruce/Oregon Grape)



Distribution.—PIPU/BERE is a major type within the *Picea pungens* series and is found throughout the study area, except for the LaSal, Abajo, and Pine Valley Mountains. It occupies a variety of aspects from 7,800 to 9,000 feet (2 380 to 2 740 m) in elevation. Typical sites are cool and dry steep midelevation slopes or benches. Many have undulating terrain. This type represents the zone of climatic climax for *Picea pungens*; its distribution at lower elevations is usually associated with riparian systems. PIPU/BERE may border ABCO/BERE, PSME/BERE, or ABLA/BERE at the higher elevation extremes.

Vegetation.—Although *Picea pungens* is the climax tree, *Pseudotsuga menziesii, Pinus flexilis*, and *Populus tremuloides* may dominate as seral associates in relatively open stands. In some places, *Pinus ponderosa* may also persist and might deserve recognition as a separate phase. The undergrowth is characterized by a dominance of shrubs. The low canopy consists of *Berberis repens, Juniperus communis, Pachistima myrsinites, Ribes cereum, Rosa woodsii, Symphoricarpos oreophilus*, and *Artemisia tridentata* ssp. *vaseyana*. The herbaceous stratum is normally depauperate; only *Achillea millefolium, Poa fendleriana*, and the ubiquitous *Carex rossii* have relatively high constancy but low average cover.

Soils.—Parent materials are variable, depending upon geographic locale, and include limestone and dolomite, Tertiary and Cretaceous sandstones, basalt and andesite (appendix F). Most sites are in colluvium or residual material. Surface textures range from sandy loam to clay loam (appendix G); the majority are in the finer classes. Most sites have some exposed rock and bare soil, although the amounts are not extreme. Litter accumulations average 0.9 inch (2.4 cm).

Productivity/management.—Timber potentials are very low (appendixes D and E). In the more moderate extremes of this h.t., small clearcuts and shelterwood systems may be successful for regeneration of *Picea pungens* and *Pseudotsuga menziesii*. Site index is relatively high for both *P. pungens* and *Pinus ponderosa*, but stocking limitations will reduce yields. There also appear to be opportunities for managing *Populus tremuloides* within this h.t. Big game use will normally be restricted to seasonal hiding and thermal cover; only limited browse is available. Domestic livestock will find only negligible herbage, usually in association with seral *P. tremuloides* communities.

Other studies.—Pfister (1972) first suggested the presence of a PIPU/BERE h.t. in southern Utah, although he provided no description. Kerr and Henderson (1979) described the type from the northern portion of the Wasatch Plateau. This treatment divides their concept, resulting in this and the PIPU/JUCO h.t.'s. PIPU/BERE also extends into northern Utah, where it occurs locally in the southeastern Uinta Mountains (Mauk and Henderson 1984). Their stands contain *Pinus contorta*, missing from southern Utah, and a somewhat expanded shrub association. A *Picea pungens-Pseudotsuga menziesii* h.t. with several phases has been described for parts of Arizona and New Mexico (Moir and Ludwig 1979) that environmentally resembles PIPU/BERE, although it contains greater variability in the shrub and forb components and lacks *Pinus ponderosa*.

Pinus flexilis-Pinus longaeva Series

Distribution.—The *Pinus flexilis-Pinus longaeva* series occurs throughout the study area and denotes some of the driest sites capable of supporting trees other than *Juniperus*. It can be found on all aspects but is more common on southwest exposures on steep convex slopes and ridges between 9,000 and 10,200 feet (2 740 and 3 100 m). At the lower elevations, the series may form the lower timberline zone merging with savannalike *Juniperus* or *Cercocarpus* woodlands. More commonly, it represents a topographic or edaphic climax within the *Abies lasiocarpa* and upper *Pseudotsuga menziesii* zones.

Vegetation.—The series is named for the tentative union of two climax trees, *Pinus flexilis* and *Pinus longaeva*. Bailey (1970) and Cronquist and others (1972) recently showed that *P. longaeva* is sufficiently different from typical *Pinus aristata* in needle characteristics, thus warranting a new name, *P. longaeva*, based upon age of the individuals. Probably just as important is the distribution of the two species. *P. aristata* is more common in the easternmost ranges of the Colorado Rockies and into New Mexico, while *P. longaeva* occurs from eastern California through southeastern Nevada and into central Utah; thus, the ranges do not overlap (Eyre 1980). *Pinus flexilis* and *P. longaeva* are both long-lived, with *P. flexilis* reaching 2,500 years and *P. longaeva* at least 4,000 years. Natural regeneration of *P. flexilis* appears to be closely associated with caching of the large wingless seeds, primarily by Clark's nutcracker *(Nucifraga columbiana)* (Lanner and Vander Wall 1980). Germination of cached seeds often results in the multiple-stemed clumps characteristic of these sites, although the species may produce multiple stems from boles damaged near the ground. Germination and rooting will sometimes be restricted to crevices in rock. *Pinus longaeva* has smaller, winged seeds and should be wind disseminated. However, caching by nutcrackers does take place, especially when other *Pinus* species are also available (Dr. Ronald Lanner, Utah State University, pers. comm.).

Scattered, open-grown *Pseudotsuga menziesii* often occur as a common associate of the *Pinus flexilis-Pinus longaeva* series. Its presence can usually be interpreted as indicating the more moderate extremes of the series. On the most severe sites, *Pseudotsuga menziesii* may be accidental or absent, and the more intolerant and drought-resistant *Pinus* species will persist (fig. 13). With increasing moisture, *P. menziesii* may gain a competitive edge over *P. flexilis*. The resulting ecotone between this series and the warm and dry *Pseudotsuga* h.t.'s such as PSME/CEMO, PSME/CELE, and PSME/SYOR may be somewhat tenuous. Other occasional associates of the series include seral clones of *Populus tremuloides* and scattered *Juniperus scopulorum*.

Undergrowth within the *Pinus flexilis-Pinus longaeva* series is extremely diverse and thus does not allow clear h.t. distinctions. Most sites are characterized as shrubby and support scattered *Symphoricarpos oreophilus*, *Juniperus communis*, *Cercocarpus ledifolius*, *Cercocarpus montanus*, *Ribes cereum*, *Berberis repens*, *Rosa woodsii*, or *Haplopappus suffruticosus*. Less often the shrub stratum is missing, and bunchgrasses such as the ubiquitous *Carex rossii*, and *Leucopoa kingii*, *Elymus salina*, or *Muhlenbergia montana* become somewhat conspicuous. Common forbs include *Astragalus miser*, *Achillea millefolium*, *Hymenoxys richardsonii*, and, on the most mesic sites, *Thalictrum fendleri*. Two h.t.'s were tentatively considered; the diagnostic undergrowth species are *Cercocarpus ledifolius* and a union of *Juniperus communis* and *Symphoricarpos oreophilus*. However, insufficient data and overall management similarities result in no distinctions beyond the series level.

Soils.—The series occurs on a variety of substrates but is best represented on colluvium derived from limestone and dolomite or Tertiary and Cretaceous sandstone (appendix F). A characteristic feature is the predominance of bare soil; almost all sites have some and most sites have between 25 and 50 percent. Consequently, litter accumulations are slight and intermittent. Most sites are droughty with gravel in the shallow subsurface horizons. Surface textures vary depending upon parent material. Steep slopes, high-intensity summer convection storms, and only partial ground cover for interception often result in severe sheet erosion of fine particles. This usually leads to the development of gravel pavements. Additional erosion can be expected from wind action. High insolation and wind during the winter usually result in reduced snowpack accumulations. However, soils can be expected to freeze. Plant evapotranspirational stresses should be high year-long. Climatological data representative of this series are not available.

Productivity/management.—Timber potentials are very low to low and represent the poorest sites within the study area (appendix D). Even when occasional *Pseudotsuga* may have respectable site indexes, stocking reductions and regeneration failures will preclude any management attempts. Higher values include the limited watershed protection and, probably most important, wildlife habitat attributes. The series often provides key winter range for big game, especially when browse such as *Cercocarpus*, *Rosa woodsii*, and *Ribes cereum* are available. Even in years of low snowpack, sites will receive intense pressure for all available forage. As

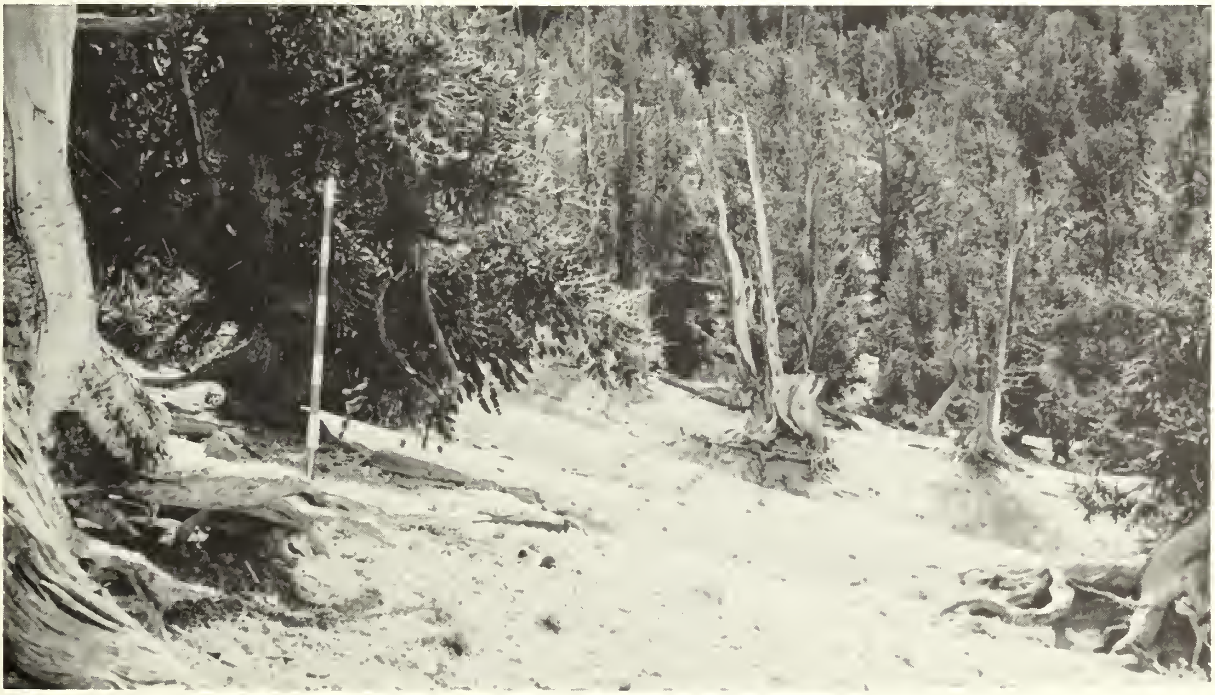


Figure 13.—A typical site within the *Pinus flexilis-Pinus longaeva* series, near Cedar Breaks National Monument on the Markagunt Plateau. The site is at 9,660 feet (2 940 m) on a southwest aspect. *Pinus longaeva* creates the canopy, with scattered *Pinus flexilis* saplings also present.

previously noted, the pinenuts provide a critical food supply for the nutcracker. Small mammals and birds may also benefit from this caching, and thus hawks and owls rely upon these sites for their prey base. Fire histories within this series are scant. Some sites show evidence of past light surface wildfires, but the effect upon undergrowth is difficult to determine. Most sites develop such low and discontinuous fuel accumulations that fire spread is negligible. Generalized successional models and hypothesized fire effects for climax *Pinus flexilis* sites in Colorado are presented by Crane (1982) and appear reasonable for many of the graminoid-dominated situations within this series in southern Utah. Her work does not appear appropriate for the more common shrub-dominated sites.

Other studies.—The *Pinus flexilis* series is present in many other areas, and h.t.'s have been described from Montana (Pfister and others 1977), central Idaho (Steele and others 1983), and northern Utah (Mauk and Henderson 1984). In central Utah, Ellison (1954) described *Pinus flexilis* communities on the Wasatch Plateau growing on dry limestone cliffs and ridges. Pfister (1972) also notes the presence of climax *P. flexilis* and briefly describes two sites supporting *Pinus longaeva* on outcrops of Wasatch limestone. Workers in Colorado have described several bunchgrass-type h.t.'s for *Pinus aristata*; these should not be confused with this series.

Pseudotsuga menziesii Series

Distribution.—Sites supporting *Pseudotsuga menziesii* as the dominant climax tree are not as common within the study areas as either *Abies lasiocarpa, Abies concolor, Picea engelmannii*, or *Pinus ponderosa*. The *Pseudotsuga menziesii* series consists of seven h.t.'s; all but two (PSME/BERE and PSME/SYOR) are considered minor or incidental. Types are generally found scattered throughout the eastern half of the study area and range in elevation from 7,200 to 9,700 feet (2 190 to 2 960 m). Typically, climax *P. menziesii* sites are on cool slopes above *P. ponderosa* and below *A. lasiocarpa* series. Occasionally the *Abies concolor* series, more common along the western flank of the Wasatch, Fish Lake, and Sevier Plateaus, will form the upper boundary with this series. Both PSME/CELE and PSME/CEMO represent lower timberline conditions and are often adjacent to shrublands.

Vegetation.—Only PSME/PHMA, PSME/BERE, and PSME/SYOR represent sites capable of supporting closed, dense stands of *Pseudotsuga menziesii*. Other h.t.'s within the series are more open and savannalike. *Populus tremuloides* or *Pinus ponderosa* are important seral associates on most sites. Undergrowth is often dominated by a variety of tall shrubs; only PSME/BERE and PSME/SYOR have open, low shrub strata.

Soils/climate.—Our series shows a strong affinity for limestones and sandstones rather than igneous parent materials (appendix F). Only PSME/SYOR is found most often on basaltic bedrock. This relationship with non-acidic substrates was first presented by Steele and others (1983) based on work in Idaho and Wyoming. It apparently also holds in northern Utah (Mauk and Henderson 1984). The *Pseudotsuga* series often represents sites with shallow, rocky soils and relatively high amounts of bare ground. Climatic patterns for the series are best represented by the Hiawatha and Joes Valley stations (appendix H). In general, this series represents cool sites with spring or early summer droughts sufficient to exclude establishment of *Abies concolor* or *Abies lasiocarpa*.

Productivity/management.—Timber management appears feasible on better sites within the PSME/BERE and PSME/SYOR h.t.'s. Shelterwood or occasionally small clearcutting systems will encourage *Pseudotsuga* regeneration if sites are protected from high insolation and wind. *Pinus ponderosa* should be favored within the PIPO phase of PSME/BERE. When silvicultural prescriptions are developed, careful consideration should be given to competition from shrubs and graminoids, stocking limitations on rocky sites, severity of *Arceuthobium douglasii* infection, and browsing by wildlife.

Fire may play an important part in shaping many stands within the *Pseudotsuga* series. The presence of *Populus tremuloides, Quercus gambelii*, and *Arctostaphylos patula* may be indicative of sites with recent fires. However, our series does not contain the common graminoids that are so important for frequent light surface fires characteristic of other areas, especially Idaho and Montana. On some sites, especially within PSME/CELE and PSME/CEMO, fires may be infrequent because of noncontinuous ground fuels. Crane (1982) presents generalized fire effects and successional trends for some Colorado types that appear appropriate for our PSME/BERE-BERE, PSME/PHMA, and PSME/SYOR h.t.'s if *Pinus ponderosa* is not present.

sedotsuga mensiesii/Physocarpus malvaceus h.t. PMSE/PHMA; Douglas-Fir/Ninebark)

Distribution.—PSME/PHMA is an incidental type conined to the northern Fish Lake and Wasatch Plateaus. t also extends along the Wasatch Front into Idaho refer to "Other studies"). It typically occurs on steep niddle to upper elevation slopes with northern aspects. Vithin the study area, sites ranged from 8,000 to 9,100 eet (2 440 to 2 780 m); lower elevations are more comnon northward. The type may be adjacent to drier, less rotected sites described by PSME/CEMO or SME/BERE. More moist sites typically belong to the *bies lasiocarpa* or *Abies concolor* series.

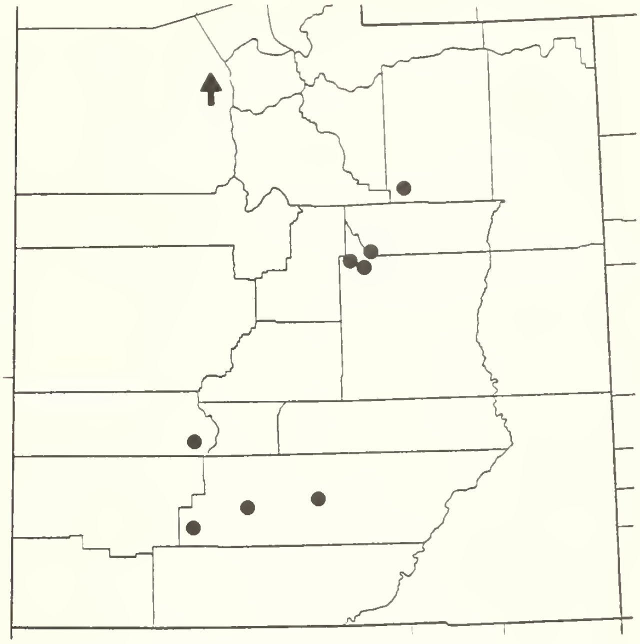
Vegetation.—*Pseudotsuga menziesii* is normally the nly conifer on the site. *Populus tremuloides* may occur s a seral associate. The undergrowth is characterized by dense layer of shrubs, including *Physocarpus alvaceus, Symphoricarpos oreophilus,* and *Amelanchier lnifolia.* These usually overtop *Berberis repens, achistima myrsinites,* and *Rosa woodsii.*

Soils.—Stands developed on coarse soils derived from mestone and sandstone. This is consistent with similar onditions throughout the PSME/PHMA h.t. outside his study area.

Productivity/management.—Timber potentials are sually low. The steep slopes, loose soils, and dense hrub layers reduce opportunities of overstory manipulaons. Best management stratagies may involve big ame habitat protection because of the hiding and theral cover associated with these sites.

Other studies.—Originally described by Daubenmire nd Daubenmire (1968) for northern Idaho, the SME/PHMA h.t. has a relatively large geographical istribution. It is a common type in Montana (Pfister nd others 1977) where a *Calamagrostis rubescens* phase, ith seral *Pinus ponderosa,* and a modal *Physocarpus* hase are identified. Two additional phases exist in cenal Idaho. The *Pinus ponderosa* and *Pseudotsuga enziesii* phases differ in their seral associations (Steele nd others 1981). A geographical variant, named for the resence of *Pachistima myrsinites,* is described from astern Idaho and western Wyoming (Steele and others 983). This phase apparently extends through northern tah (Mauk and Henderson 1984) and forms the basis r this description.

Pseudotsuga menziesii/Cercocarpus ledifolius h.t. (PSME/CELE; Douglas-Fir/Curlleaf Mountain-Mahogany)



Distribution.—PSME/CELE, a relatively minor h.t. throughout the study area, may be locally common along the eastern portion of the Wasatch Plateau. Typical sites are on steep (samples averaged 55 percent) convex to straight slopes on a variety of aspects. Elevations generally range from 8,500 to 9,300 feet (2 590 to 2 830 m), but normally represent lower timberline conditions. Nonforest communities dominated by *Cercocarpus ledifolius, Juniperus,* or *Artemisia*-steppe usually abut the lower or drier portions. Cooler, more moist sites are often influenced by soil characteristics and the abundance of surface rock and may belong to PSME/BERE.

Vegetation.—Usually *Pseudotsuga menziesii* is the dominant conifer on the site. In southern Utah, *Pinus ponderosa* becomes increasingly more important as a seral associate. These sites represent a broad transition between the more northern PSME/CELE sites and the PIPO/CELE h.t. found in the Pine Valley Mountains and Markagunt and Sevier Plateaus. Other conifers include *Juniperus scopulorum* and *Pinus edulis. Populus tremuloides* is sometimes a seral component, although it probably is responding to microsite influences in soils. The shrubby undergrowth is usually more dense than the open-canopied overstory (fig. 14) and consists of *Cercocarpus ledifolius, Symphoricarpos oreophilus, Artemisia tridentata* ssp. *vaseyana,* and *Berberis repens.* Herbaceous associates are minor and inconsistent, with only *Poa fendleriana* occurring in about half the sample stands.

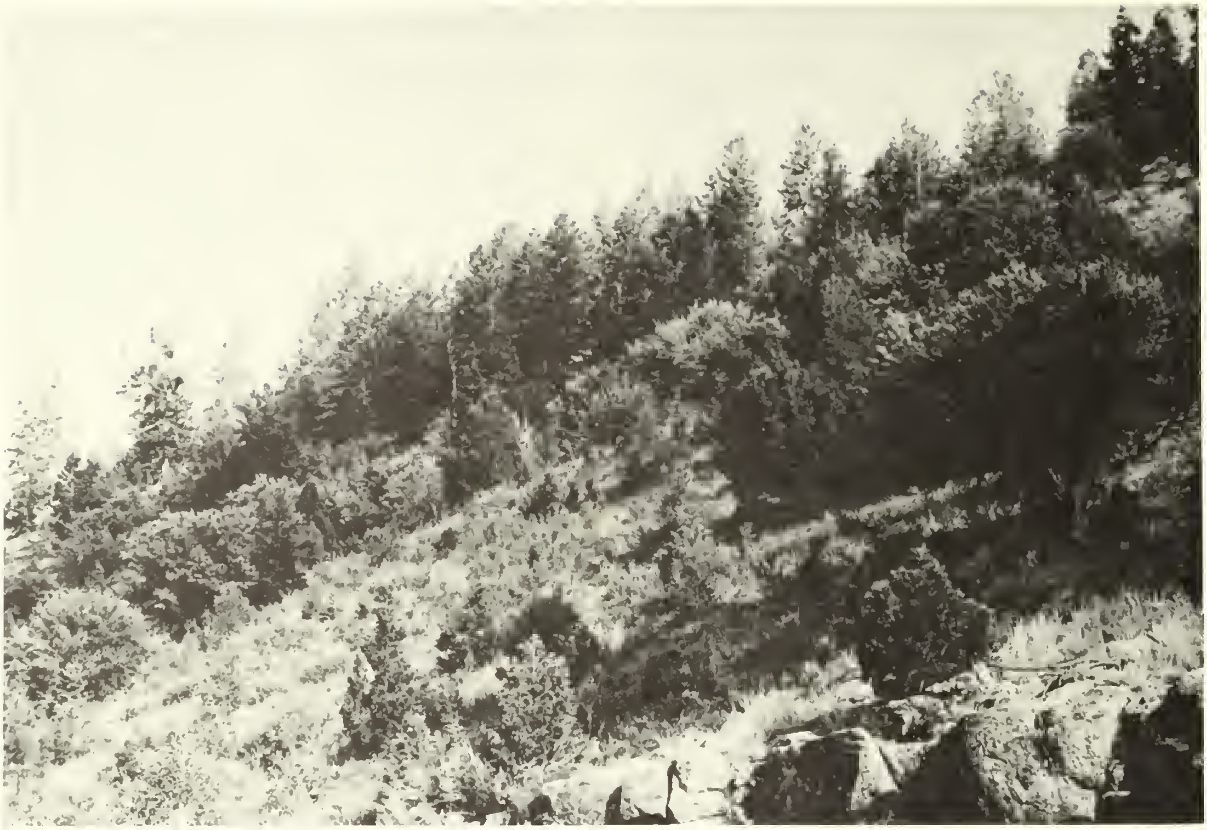


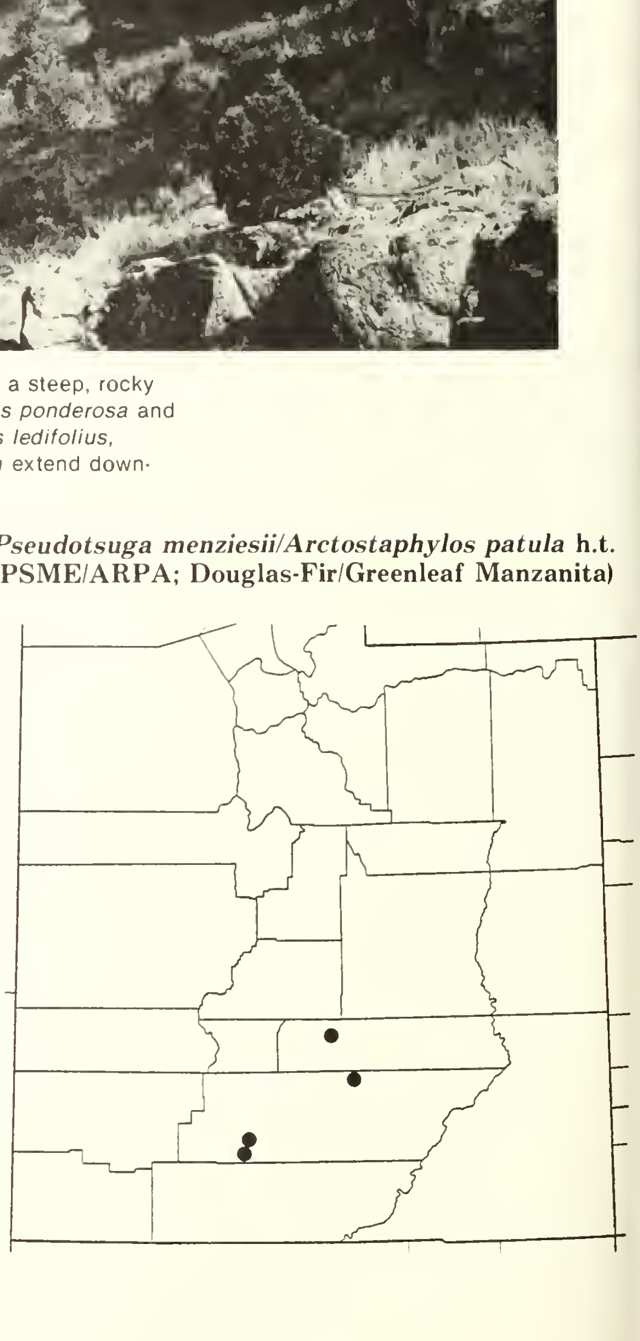
Figure 14.—*Pseudotsuga menziesii/Cercocarpus ledifolius* h.t. on a steep, rocky north slope (8,000 feet, 2 440 m) southwest of Panguitch. *Pinus ponderosa* and *Pseudotsuga menziesii* create an open overstory. *Cercocarpus ledifolius, Artemisia tridentata* ssp. *vaseyana*, and *Juniperus scopulorum* extend downward into the nonforest shrublands.

Soils.—Soil parent materials are predominantly Cretaceous and Tertiary sandstone, although igneous bedrock is also represented (appendix F). Surface textures are usually coarse. Most sites had some bare soil and exposed rock. Litter accumulations are charateristically low, averaging 0.5 inch (1.3 cm).

Productivity/management.—Timber potentials are very low (appendix D). Low stocking, rocky steep slopes, and droughty soils will hamper any regeneration attempts. The PSME/CELE should provide high quality seasonal big game habitat, especially for deer.

Other studies.—PSME/CELE was first described from central Idaho (Steele and others 1981) and eastern Idaho (Steele and others 1983). It also occurs sporadically throughout the Wasatch and Stansbury Ranges of northern Utah (Mauk and Henderson 1984).

Pseudotsuga menziesii/Arctostaphylos patula h.t. (PSME/ARPA; Douglas-Fir/Greenleaf Manzanita)



Distribution.—The PSME/ARPA is a minor h.t. confined to the Paunsaugunt and southern Fish Lake Plateaus and the Escalante and Boulder Mountains. It usually occurs on steep, undulating middle to lower slopes between 7,200 and 8,700 feet (2 190 and 2 650 m). It can be found on a variety of aspects but most typically on eastern and western aspects at the lower range of the *Pseudotsuga menziesii* series. As such, it represents a broad ecotone with the *Pinus ponderosa* series and most likely the PIPO/ARPA or PIPO/QUGA h.t.'s and the cooler PSME/SYOR, PSME/QUGA, or PSME/BERE h.t.'s or *Abies concolor* series.

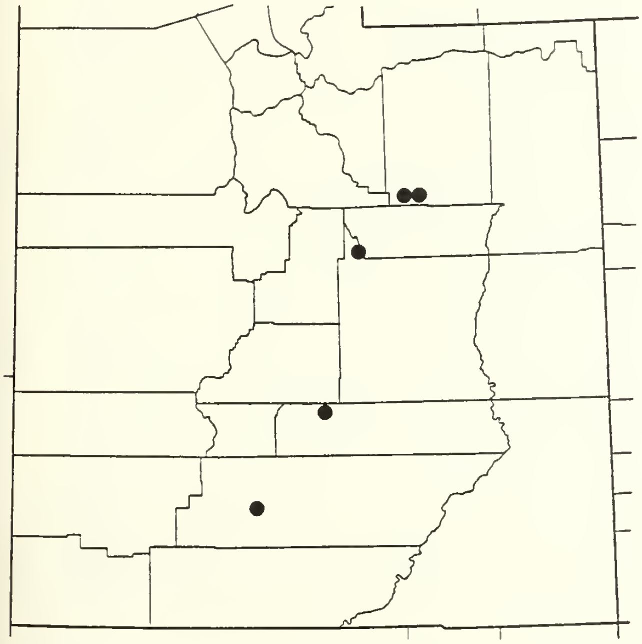
Vegetation.—Both *Pseudotsuga menziesii* and *Pinus ponderosa* dominate the overstory, often with *P. ponderosa* more abundant. *Juniperus scopulorum* is usually present, and *Pinus flexilis* may also be found. A low, dense shrub layer consists of *Arctostaphylos patula, Berberis repens, Ceanothus martinii*, and *Symphoricarpos oreophilus*. Forbs and graminoids are usually sparse.

Soils.—Parent materials are usually sandstones and limestones. Surface soil horizons usually contain gravels and stones. Surface textures are loam to sandy loam.

Productivity/management.—Timber potentials are apparently low, resulting from low site index for both *Pseudotsuga menziesii* and *Pinus ponderosa* and from stocking limitations. *Arceuthobium douglasii* appears to present management problems within this type.

Other studies.—No other studies have described the PSME/ARPA h.t.

Pseudotsuga menziesii/Cercocarpus montanus h.t. (PSME/CEMO; Douglas-Fir/Mountain-Mahogany)



Distribution.—PSME/CEMO is a minor h.t. occurring throughout the eastern half of the study area on steep, rocky, northern aspects at midslope positions. Elevations range from 7,200 to 8,200 feet (2 190 to 2 500 m) and represent the lower bounds of the *Pseudotsuga* series. Adjacent, more moist sites normally belong to PSME/BERE; drier sites are often *Juniperus* woodlands.

Vegetation.—Open stands of *Pseudotsuga menziesii* dominate sites, often with *Pinus edulis, Juniperus scopulorum*, and *Juniperus osteosperma* scattered throughout. A low canopy of shrubs, including *Cercocarpus, Shepherdia rotundifolia, Berberis repens*, and *Symphoricarpos oreophilus*, dominates the relatively open undergrowth. *Carex rossii* and *Oryzopsis hymenoides* are often present in trace amounts. Forb cover is inconsistent.

Soils.—Most sampled sites occur on sandstone. There is usually a high amount of surface rock. Bare soil may exceed 50 percent, apparently more than all other types within the study area. In contrast, litter accumulations may be the lowest for all types. Surface soil textures are coarse.

Productivity/management.—Timber potentials are very low. Poor stocking, rocky sites, and steep slopes limit management opportunities. This type probably has high value for big game habitat, providing key browse and seasonal cover requirements. It may be especially important in some areas for spring and fall range for mule deer (Smith and Julander 1953).

Other studies.—Similar plant communities have been described in Colorado (Terwilliger and others 1979). This h.t. has not been previously described.

Pseudotsuga menziesii/Quercus gambelii h.t. (PSME/QUGA; Douglas-Fir/Gambel Oak)

Distribution.—PSME/QUGA is an incidental h.t. occurring in the extreme southern portions of the Abajo Mountains and the Aquarius Plateau. It also extends into Colorado and New Mexico (refer to "Other studies"). Sites range from 7,500 to 9,100 feet (2 290 to 2 770 m) on steep slopes having northern to northwestern aspects. Adjacent cooler sites may belong to the PSME/BERE h.t. Warmer sites often belong to the *Pinus ponderosa* series.

Vegetation.—*Pinus ponderosa* and *Pseudotsuga menziesii* dominate seral stands. Trees are usually widely spaced, especially in more mature conditions. *Juniperus scopulorum* may also be present in minor amounts. The undergrowth is dominated by shrubs, especially *Quercus gambelii* and *Symphoricarpos oreophilus*. *Quercus* may also assume a more treelike appearance. *Arctostaphylos patula, Berberis repens, Rosa woodsii*, and *Ribes cereum* may also occur, usually in minor amounts. Graminoids, including *Carex rossii, Poa fendleriana, Koeleria nitida*, and *Sitanion hystrix*, have high constancy but low average cover. Forbs are usually absent.

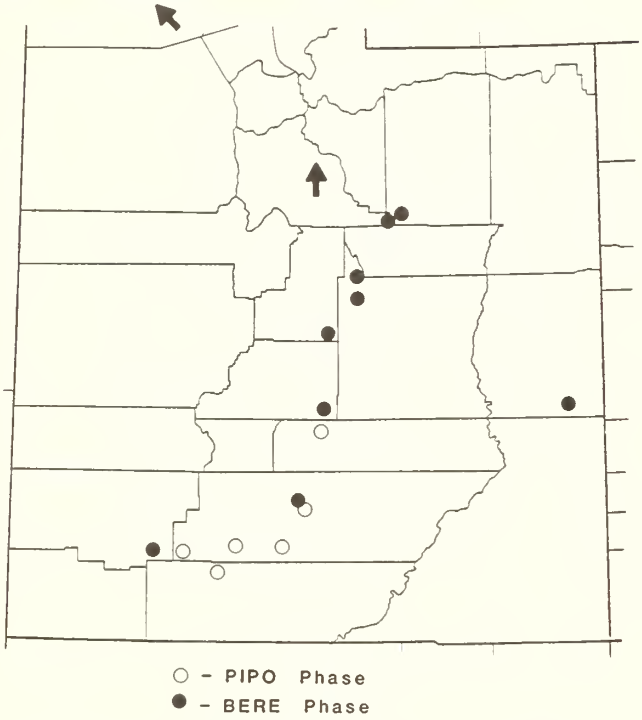
Soils.—Parent materials consist of mixed sandstones, basalts, and andesites. Surface textures range from sandy loam to loam. Subsurface horizons contain gravels and cobbles.

Productivity/management.—Timber potentials are usually low, resulting from site index and stocking limitations. The structural characteristics—that is, vertical diversity of shrubs—may be important for many avian wildlife species. *Quercus* mast and browse are also important for many game species.

Other studies.—Similar conditions have been described from western Colorado (Boyce 1977) and south-central Colorado (Terwilliger and others 1979). The

PSME/QUGA h.t., with phasal distinctions of *Festuca arizonica*, has also been described from northern New Mexico and southern Colorado (DeVelice and others in press).

Pseudotsuga menziesii/Berberis repens h.t. (PSME/BERE; Douglas-Fir/Oregon Grape)



Distribution.—The PSME/BERE h.t. is a major type within the *Pseudotsuga menziesii* series. It occurs sporadically across the Markagunt, Paunsaugunt, Aquarius, and Fish Lake Plateaus and the LaSal Mountains and extends northward throughout the eastern side of the Wasatch Plateau into the Tavaputs Plateau and northern Utah. Sites range from 7,800 to 9,700 feet (2 380 to 2 960 m), and average 9,260 feet (2 820 m) on southwest aspects, 8,800 feet (2 680 m) on northeast aspects, and 8,000 feet (2 440 m) on north aspects. Occurrence on southern and southeastern aspects is relatively uncommon. Slopes are usually steep and straight. This type generally represents middle to upper elevations within the *Pseudotsuga menziesii* series and may be surrounded by cooler, more moist h.t.'s within the *Abies lasiocarpa* or *Abies concolor* series, or warmer sites belonging to the PSME/CELE or PSME/QUGA h.t.'s or the *Pinus flexilis-Pinus longaeva* series.

Vegetation.—*Pseudotsuga menziesii* is the dominant tree. *Juniperus scopulorum* and *Populus tremuloides* may be present as seral species. The normally depauperate undergrowth is characterized by a moderate cover of low shrubs consisting of *Berberis repens*, *Symphoricarpos oreophilus*, and sometimes *Pachistima myrsinites*. Other features vary with the phases noted below.

Pinus ponderosa (PIPO) phase: This phase is more common on steep middle to lower slopes, usually about 600 feet (180 m) below adjacent BERE phase sites. It is restricted to the southern portion of the range of the h.t., apparently not extending north into the Wasatch Plateau or east into the LaSal Mountains. *Pinus ponderosa* is a long-lived seral dominant within this phase. *Juniperus communis* and *Amelanchier alnifolia* are usually present in small amounts. The herbaceous stratum is noticeably absent, with only *Carex rossii* and *Sitanion hystrix* usually present in trace amounts.

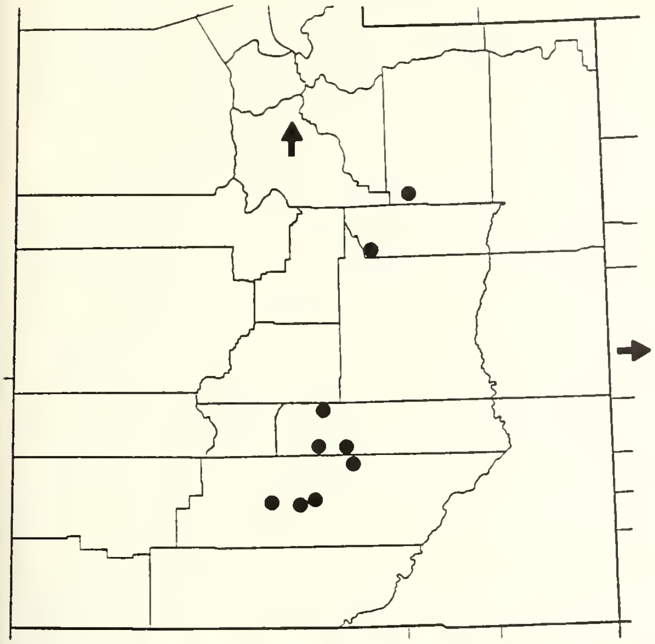
Berberis repens (BERE) phase: The BERE phase is the more common phase throughout the study area, except for the extreme southern plateaus. *Picea pungens* may be found as accidentals, and *Pinus flexilis* may occur as a seral component. In contrast to the PIPO phase, *Sitanion hystrix* is more uncommon. The herbaceous stratum is only slightly more developed, consisting of small amounts of *Stipa lettermannii*, *Thalictrum fendleri*, *Osmorhiza chilensis*, and *Lathyrus* species.

Soils.—Soil parent materials are mainly Cretaceous and Tertiary sandstones in the BERE phase, while the PIPO phase occurs on a wide mixture of types, including sandstone and limestones, basalts, and andesites (appendix F). The PIPO phase apparently represents more severe environmental conditions, with about 11 percent surface rock exposed and 6 percent bare soil, and surface textures ranging from loam to silt loam. Most sample sites had significant amounts of gravel and stones in the subsurface. Sites belonging to the BERE phase usually have only about 7 percent surface rock exposed, similar amounts of bare soil, and surface textures from loam to clay loam. There is also a slight increase in litter accumulation, averaging about 1.3 inches (3.2 cm).

Productivity/management.—Timber potentials are generally low (appendixes D and E). *Pseudotsuga menziesii* may respond favorably to small clearcuts that provide protection from wind and insolation. Light shelterwood systems may also be appropriate, especially in the BERE phase. *Pinus ponderosa* presents limited opportunities for uneven-aged management within the PIPO phase. Many of the sampled stands within this h.t. were infected with *Arceuthobium douglasii*, which will influence management alternatives. Deer apparently make heavy use of this h.t., especially when natural openings that provide forage are nearby. Domestic livestock will usually find little forage within this type.

Other studies.—PSME/BERE is a widespread type with different phases in the northern Rockies, with previous descriptions from central Idaho (Steele and others 1981) and eastern Idaho and western Wyoming (Steele and others 1983). It also extends into northern Utah (Mauk and Henderson 1984). This treatment of our study area combines the SYOR and BERE phases of northern Utah and presents the PIPO phase as a new subdivision.

Pseudotsuga menziesii/Symphoricarpos oreophilus h.t. (PSME/SYOR; Douglas-Fir/Mountain Snowberry)



Distribution.—PSME/SYOR is a major h.t. in southern Utah that occurs mainly on the southern Fish Lake and Aquarius Plateaus and the Boulder Mountains. A somewhat disjunct distribution also occurs sporadically along the northeastern portion of the Wasatch Plateau and the Tavaputs Plateau. The type is most commonly found on straight and steep northern slopes between 8,000 and 9,300 feet (2 440 and 2 830 m). It represents middle to upper elevations for the *Pseudotsuga menziesii* series. Warmer and drier adjacent sites may belong to PSME/BERE-PIPO or PIPO/SYOR. Benches with cold air accumulation may belong to PIPO/PUTR or PIPU/JUCO. More moist conditions usually will support *Abies lasiocarpa.*

Vegetation.—Open stands of *Pseudotsuga menziesii* dominate the site. *Pinus ponderosa* and *Populus tremuloides* may be present as important seral components. *Juniperus scopulorum* is also usually present, either as a seral or minor climax associate. A light shrub canopy of *Symphoricarpos*, with trace amounts of *Berberis repens, Rosa woodsii*, and *Ribes cereum*, dominate the undergrowth (fig. 15). The normally depauperate herbaceous stratum may contain trace amounts of *Carex rossii, Poa fendleriana, Sitanion hystrix*, and *Hymenoxys richardsonii.*

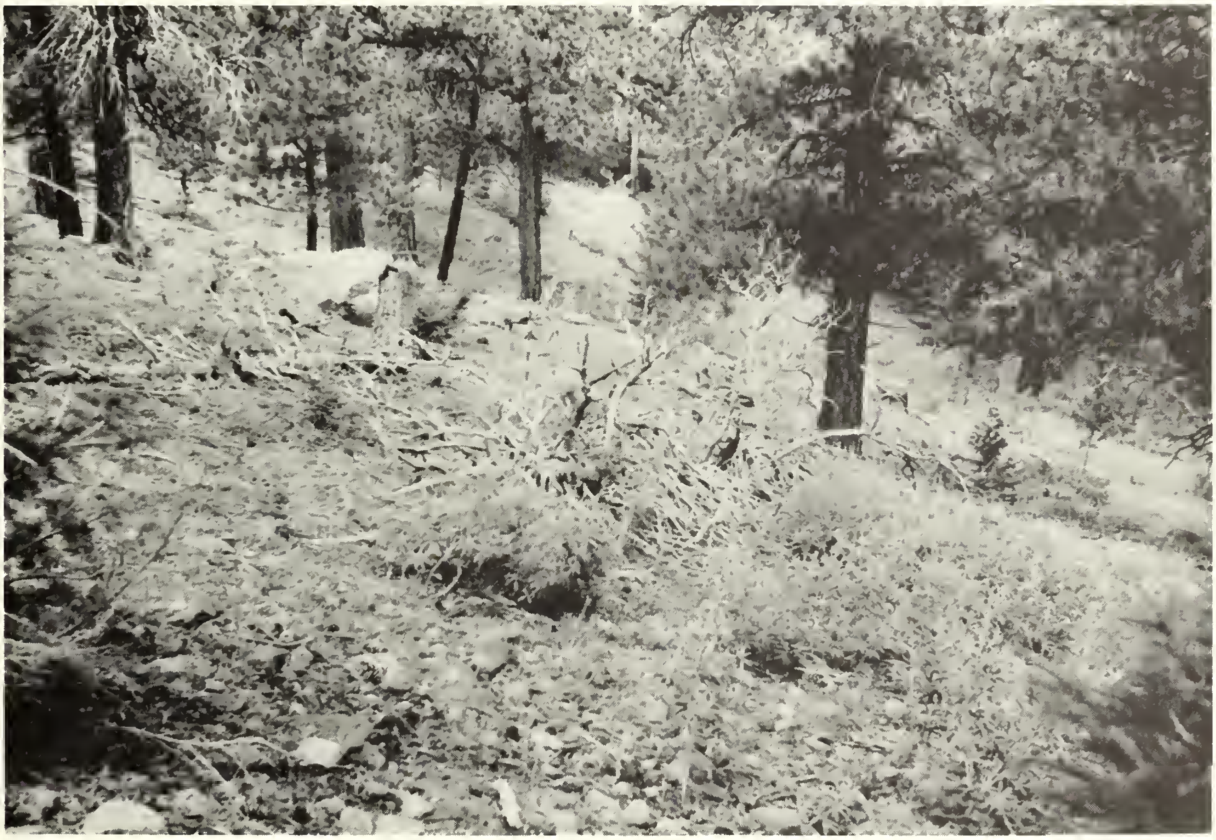


Figure 15.—*Pseudotsuga menziesii/Symphoricarpos oreophilus* h.t. on a steep northwest slope (8,850 feet, 2 700 m) near Wildcat Pasture in the Boulder Mountains. *Pinus ponderosa* creates an open canopy in the overstory; *Pseudotsuga menziesii* is scattered throughout the understory. The undergrowth consists of *Symphoricarpos oreophilus, Poa fendleriana*, and *Lupinus argenteus.*

Soils.—Parent materials for the PSME/SYOR h.t. appear to be predominantly basaltic, although a few sites in the Tavaputs Plateau occurred on Tertiary and Cretaceous sandstone (appendix F). Deposition is usually colluvial. Surface rock exposed averages 10 percent, and most sites have bare soil, averaging 11 percent. Litter accumulations are highly variable, ranging from none to 3.9 inches (10 cm), and averaging 1.3 inches (3.4 cm). Soil textures range from sandy loam to clay loam (appendix G).

Productivity/management.—Timber potentials are low (appendix D). Low site indexes for *Pseudotsuga menziesii* and *Pinus ponderosa*, and stocking limitations, reduce potential yields. Most stands have had repeated moderate to heavy ground fires, and *P. menziesii* has regenerated under the natural shelterwood conditions. *Arceuthobium douglasii* is present in many stands. Big game, especially deer, may make seasonal use of these sites.

Other studies.—The PSME/SYOR h.t. is a major type throughout the northern and middle Rocky Mountains. Its presence has been noted for Montana (Pfister and others 1977), central Idaho (Steele and others 1981), eastern Idaho and western Wyoming (Steele and others 1983), and northern Utah (Mauk and Henderson 1984). Somewhat similar conditions exist in Colorado (Komarkova 1982; Hess and Wasser 1982).

Pinus ponderosa Series

Distribution.—The *Pinus ponderosa* series is a major group of h.t.'s found throughout southern Utah. Scattered sites on the Tavaputs Plateau also belong to this series. It occupies warm and dry exposures through an elevational belt ranging from about 6,800 to 9,000 feet (2 070 to 2 740 m). Slopes are generally gentle to moderately steep; only PIPO/ARNO and sometimes PIPO/PUTR tend to occur in flat benches. The series usually represents the lowest coniferous forests in the area and borders unclassified communities such as *Juniperus scopulorum* woodlands or *Cercocarpus ledifolius, Arctostaphylos patula, Artemisia,* or *Quercus gambelii* shrubfields. These often resemble the undergrowth of the adjacent forested communities. The upper boundary or cooler, more moist sites, are recognized by the presence of more tolerant species of conifers such as *Abies concolor* or *Pseudotsuga menziesii*. Again, changes in the undergrowth may not coincide with the climax overstory, and the ecotone between PIPO/ARPA, PIPO/QUGA, PIPO/CELE, and PIPO/SYOR and their counterparts in the *Pseudotsuga menziesii* or *Abies concolor* series may be relatively broad and indefinite. When the series abuts lower elevation sites within the *Picea pungens* series, the demarcation is usually more abrupt.

Vegetation.—The structure of mature stands varies from rather open in PIPO/MUMO, PIPO/ARNO, and PIPO/ARPA to locally dense in the PIPO/QUGA and PIPO/SYOR. All of our h.t.'s represent sites potentially capable of supporting at least 25 percent canopy cover of trees, thus constituting open forests rather than true savanna as used by other researchers (Pfister and others 1977; Mauk and Henderson 1984). Although *Pinus ponderosa* is normally the only conifer, stands may sometimes contain significant amounts of *Juniperus scopulorum, Juniperus osteosperma,* or *Pinus edulis. Populus tremuloides*, so important in other series, is poorly represented here, occurring in only small amounts within the PIPO/QUGA and PIPO/SYOR h.t.'s. Mature stands range in age from about 100 years for PIPO/CELE to 200 years for PIPO/MUMO and PIPO/QUGA.

The undergrowth is conspicuously shrubby. Only PIPO/MUMO lacks a diagnostic woody stratum and resembles the open grassy undergrowth so characteristic of *P. ponderosa* stands in Arizona and New Mexico.

Soils/climate.—Soils are usually derived from igneous parent material, including basalt, basaltic and andesitic flows, intrusive granitoids and porphyrites, and tuffs (appendix F). Only PIPO/ARPA and PIPO/QUGA occur more commonly on nonigneous substrates such as limestone, dolomites, and various sandstones. Surface textures are highly variable and range from sand in PIPO/ARPA to predominantly loam in PIPO/ARNO and loam and silt loam in PIPO/MUMO (appendix G). All types contain some bare soil and exposed rock, with relatively extreme amounts in PIPO/ARPA. Litter accumulations are fairly consistent between types, only ranging from 1.1 inches (2.8 cm) in PIPO/ARPA to 1.9 inches (4.9 cm) in PIPO/QUGA.

Climatic data for the series are best represented by the Bryce Canyon National Park Headquarters, Monticello, and Orange Olsen reporting stations (appendix H). The Bryce Canyon and Orange Olsen stations are at the upper extent of the series, while Monticello is at the lower extreme. In general, this series receives significant precipitation during the warm growing season, especially during August and early September. Mean annual temperatures appear to be above 40.1 °F (4.5 °C), and mean annual precipitation is less than 15.6 inches (390 mm).

Productivity/management.—The *Pinus ponderosa* series presents unusual management opportunities and problems for the resource specialist. Timber values range from very low to low and appear best in the PIPO/SYOR and PIPO/QUGA h.t.'s (appendixes D and E). Almost all sites have limitations of some degree as a result of poor stocking, unfavorable soil moisture conditions, or competition from undergrowth vegetation. As a general guideline, group selection or shelterwood systems should provide the best chance for successful regeneration. Some sites, especially in the PIPO/MUMO, PIPO/QUGA-SYOR, PIPO/ARPA, and maybe PIPO/ARNO h.t.'s, may support *Pinus ponderosa* severely damaged from the dwarf mistletoe *Arceuthobium vaginatum* ssp. *cryptopodum*. Work in southwestern Colorado (Merrill 1983) has shown a positive relationship between severity of dwarf mistletoe infection and environmental factors such as slope, elevation, and topography, as expressed by different h.t.'s. *Arceuthobium vaginatum* occurred more often and more severely on the driest sites where temperatures and insolation were the greatest. Heidmann (1983) presents recommendations for silvicultural prescriptions appropriate to mature stands of *P. ponderosa* heavily infected with dwarf mistletoe, but these appear feasible only in sites with the highest timber potentials. Throughout the series, mountain pine beetle (*Dendroctonus ponderosae*) may also infest stands and influence timber management.

Fire has played an important part in stand development for most of the h.t.'s in this series. The exception might be sites within the PIPO/ARNO or PIPO/PUTR h.t.'s, where discontinuous ground fuels may prevent the normal surface fires. Fire histories of the area are scarce and difficult to categorize by h.t. Research in Zion National Park may be applicable to the PIPO/ARPA and PIPO/QUGA h.t.'s and suggests a normal time interval between 4 and 7 years prior to 1882 (Madany 1981; Madany and West 1980, 1983). After this date, livestock grazing may have reduced fine fuels, allowing shrub densities to increase with a resulting increase in the fire interval. This apparently occurred before fire prevention programs became effective. Field data from the isolated areas receiving no livestock grazing still indicate sufficient canopy coverage of shrubs to easily determine the h.t. and help indicate the potential conditions for mature stands. Crane (1982), based on work from Colorado, gives more detailed descriptions of fire effects for vegetation and hypothesized successional trends following fire that appear reasonable for our PIPO/QUGA, PIPO/MUMO, and PIPO/PUTR h.t.'s. Short-term responses of birds and mammals to prescribed burning in *P. ponderosa* have been reported by Bock and Bock (1983).

Livestock grazing is an important management concern for many of the h.t.'s within this series. Almost all sites show evidence of past grazing disturbance to some degree, and ecological and successional relationships are often unclear. Many mature, uneven-aged stands of *P. ponderosa* contain relatively high coverages of disturbance species such as *Sitanion hystrix*, which may have increased when other more palatable species were consumed. Also present in many h.t.'s is the perennial composite *Hymenoxys richardsonii*, which may be toxic to sheep and cattle (Hermann 1966). In general, our series lacks the grassy undergrowth that constitutes high quality range.

Wildlife habitat values within the series are highly variable and are best discussed by h.t. Structural characteristics may be important for a variety of small mammal and avian species, while big game usually find abundant browse, especially in the PIPO/CELE, PIPO/ARPA, PIPO/QUGA, and sometimes PIPO/PUTR h.t.'s.

Other studies.—The *Pinus ponderosa* series is extensive throughout the Rocky Mountains. Relationship to other areas is discussed by h.t. but generally is highest with adjacent portions of Colorado. Several types have somewhat disjunct distributions, with extensions in central Idaho and south-central Oregon.

Pinus ponderosa/Cercocarpus ledifolius h.t. PIPO/CELE; Ponderosa Pine/Curlleaf Mountain-Mahogany)

Distribution.—PIPO/CELE is a minor h.t. within the study area and occurs on the Tavaputs Plateau in the north and in the Markagunt and Sevier Plateaus and Pine Valley Mountains in the south. It can be found on all aspects and ranges from 6,800 to 8,100 feet (2 070 to 2 470 m) in elevation on gentle to moderately steep lower slopes and benches. It usually represents the lowest elevation sites within the *Pinus ponderosa* series and may be adjacent to *Juniperus* woodlands. Cooler sites may belong to PIPO/QUGA, PSME/CELE, or ABCO/CELE, although these are often found on different geological substrates.

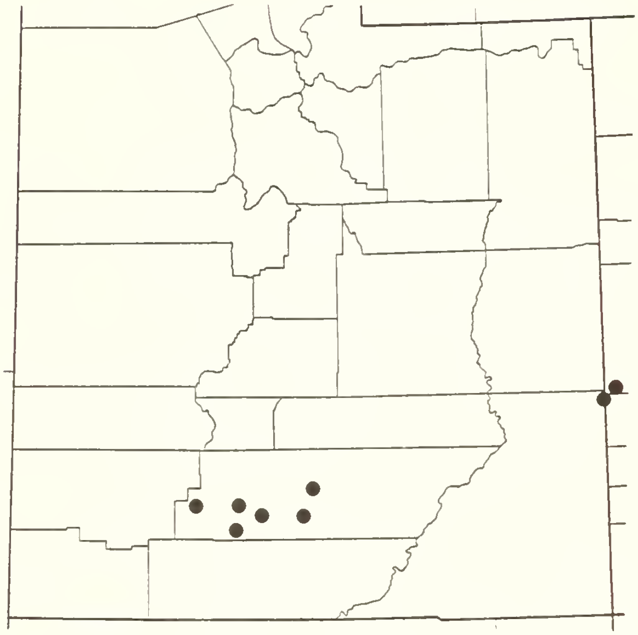
Vegetation.—*Pinus ponderosa* creates an open canopy, usually accompanied by *Juniperus scopulorum* and sometimes *Pinus edulis. Abies concolor* and *Pseudotsuga menziesii* may appear as accidentals. The dense undergrowth is conspicuously shrubby and consists of *Cercocarpus ledifolius, Juniperus osteosperma, Quercus gambelii, Chrysothamnus viscidiflorus, Artemisia tridentata*, and *Symphoricarpos oreophilus*. Forbs and graminoids are noticeably absent, with only *Sitanion hystrix* and *Eriogonum racemosa* having fairly high constancy. Sites on the Tavaputs Plateau may contain modest cover of *Elymus salina*, while those in southwestern Utah appear to support *Stipa comata*.

Soils.—PIPO/CELE on the Tavaputs Plateau occurs on Tertiary sandstone, while sites in the southwestern portion of the study area are on andesite. Regolith is either residual or colluvium. Sites have relatively low amounts of bare soil and exposed surface rock, and litter accumulations average 1.5 inches (3.9 cm). Surface textures are mostly loam and sandy loam. Most sites have gravelly coarse fragments.

Productivity/management.—Timber potentials appear to be very low. Individual trees may have widely varying site indexes, but stocking limitations will greatly reduce yields. Competition from shrubs may severely limit regeneration efforts. Most sites contain evidence of grazing by domestic livestock, although only limited forage is available. This h.t. should be key seasonal habitat for deer because of available browse and low elevation.

Other studies.—Outside our study area, several workers have described plant communities dominated by *Pinus ponderosa* and *Cercocarpus ledifolius* in south-central Oregon on dry residual soils (Franklin and Dyrness 1973). These communities also contained *Festuca idahoensis*, indicating slightly cooler and more moist conditions than in our study area. No other workers have described the PIPO/CELE h.t.

Pinus ponderosa/Arctostaphylos patula h.t. (PIPO/ARPA; Ponderosa Pine/Greenleaf Manzanita)



Distribution.—PIPO/ARPA, a major h.t. with the *Pinus ponderosa* series, occurs in large acreages within the southern portion of the study area. It can also be found in the LaSal and Abajo Mountains to the east. It represents warm and dry conditions on gentle to moderate middle to lower slopes, benches, and ridges between 7,500 and 8,500 feet (2 290 and 2 590 m). Southwest aspects are most common, although a variety are represented. Cooler, more moist adjacent sites may belong to PIPO/QUGA, PIPO/PUTR, or PSME/ARPA h.t.'s. Warmer sites are often *Juniperus* woodlands.

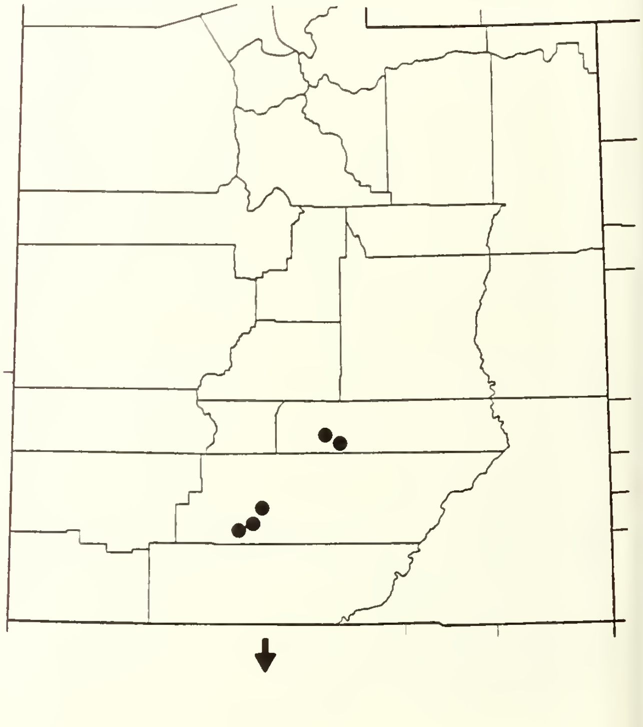
Vegetation.—Usually *Pinus ponderosa* and small amounts of *Juniperus scopulorum* are the only trees present in relatively open stands. *Pinus flexilis* and *Pseudotsuga menziesii* may occur as accidentals; successful reproduction by these species will indicate the PSME/ARPA h.t. The open undergrowth is conspicuously shrubby and consists of *Arceuthobium patula, Quercus gambelii, Berberis repens, Ceanothus martinii, Purshia tridentata*, and *Tetradymia canescens*. The herbaceous stratum is depauperate, with only small amounts of *Carex rossii, Oryzopsis hymenoides*, and *Eriogonum racemosa* occurring in about half the sites.

Soils.—Parent materials for PIPO/ARPA are diverse and include limestones, sandstones, and a few sites on basalt and andesite (appendix F). Most soils are in colluvium, although a few also occur in alluvial material. Bare soil is the highest for the series and averages 13 percent. Most sites have gravelly subsurfaces with minor amounts of surface rock exposed. Surface textures range from sand to silt loam, with loam the most common (appendix G). Litter accumulation averages 1.1 inches (2.8 cm).

Productivity/management.—Timber potentials are generally very low (appendixes D and E). Stocking limitations and seedling competition may limit yields. Gentle terrain and the relative ease of harvesting may make these sites desirable for timber management, but successful regeneration efforts are sometimes questionable. *Arctostaphylos patula* may increase with disturbance, especially fire, although it shows greatly reduced suckering and seedling establishment following fire in southern Utah as compared with areas in California (Madany 1981). All sample sites in our study area contain evidence of deer use. Domestic livestock will find only limited forage on these sites.

Other studies.—Communities dominated by *Pinus ponderosa* and *Arctostaphylos patula* have been noted for south-central Oregon (Franklin and Dyrness 1973), but they contain significant amounts of *Abies concolor* and *Festuca idahoensis*, indicating different conditions. *Arctostaphylos patula* is a diagnostic component of a phase of the *Pinus ponderosa/Festuca idahoensis* h.t. in the Uinta Mountains (Mauk and Henderson 1984); this phase resembles our h.t. in physical site characteristics. In addition to the prominence of *Festuca*, it differs in having *Pinus contorta* and *Populus tremuloides* as principal seral associates. No other studies have identified the PIPO/ARPA h.t.

Pinus ponderosa/Artemisia nova h.t. (PIPO/ARNO; Ponderosa Pine/Black Sagebrush)



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Distribution.—PIPO/ARNO is a major h.t. within the *Pinus ponderosa* series. It represents the lower timberline zone along the Boulder and Escalante Mountains but is also likely to occur on the Sevier and Paunsaugunt Plateaus. It typically is found on gentle lower slopes or benches with a variety of aspects and ranges from 8,000 to 9,000 feet (2 440 to 2 740 m) in elevation. Nonforest communities adjacent are usually graminoid wet meadows or *Artemisia* steppe. Upland sites on steeper slopes often belong to PIPO/ARPA.

Vegetation.—The open, savannalike overstory contains predominantly *Pinus ponderosa* (fig. 16), although *Juniperus scopulorum* is usually also present. *Pinus flexilis* and *Pseudotsuga menziesii* are accidentals. The undergrowth is characterized by a low and often open shrub canopy consisting of *Artemisia nova* or *Artemisia arbuscula* with *Chrysothamnus viscidiflorus* and *Tetradymia canescens* as common associates. Taxonomy of low *Artemisia* apparently is not distinct within this type, with collected specimens often sharing attributes belonging to either *A. nova* or *A. arbuscula.* Florescence of ethanol-saturated leaf material in longwave ultraviolet light indicates closer affinities with *Artemisia nova* (Alma Winward, USDA Forest Service, Intermountain Region, pers. comm.). Coverage of graminoids and forbs is usually negligible, although this may be the result of often severe domestic livestock grazing pressure. Undisturbed sites should support a light, scattered mixture of *Bouteloua gracilis, Koeleria nitida, Poa fendleriana,* and *Eriogonum racemosa.* Disturbed sites often have *Hymenoxys richardsonii* and *Sitanion hystrix* more conspicuous.

Soils.—PIPO/ARNO is found on colluvium and sometimes alluvium derived from basalt (appendix F). A few sites are on sandstone. There are usually small amounts of exposed rock and bare soil, and litter accumulations average 1.3 inches (3.2 cm). Most soils contain gravel in the subsurface horizons, and surface textures are predominantly loam and silt loam (appendix G). Sites potentially have seasonal high water tables and even ponding. They also have shallow rooting depths due to some restrictive subsurface horizon.

Productivity/management.—Timber potentials are generally very low and are the lowest for the series (appendix D). These sites have excessive stocking limitations, and trees regenerate only occasionally. Domestic livestock may find limited forage on these sites but may congregate here for shade if water and forage is nearby.

Other studies.—Similar sites have been found in the San Juan Mountains of New Mexico (DeVelice and others in press).

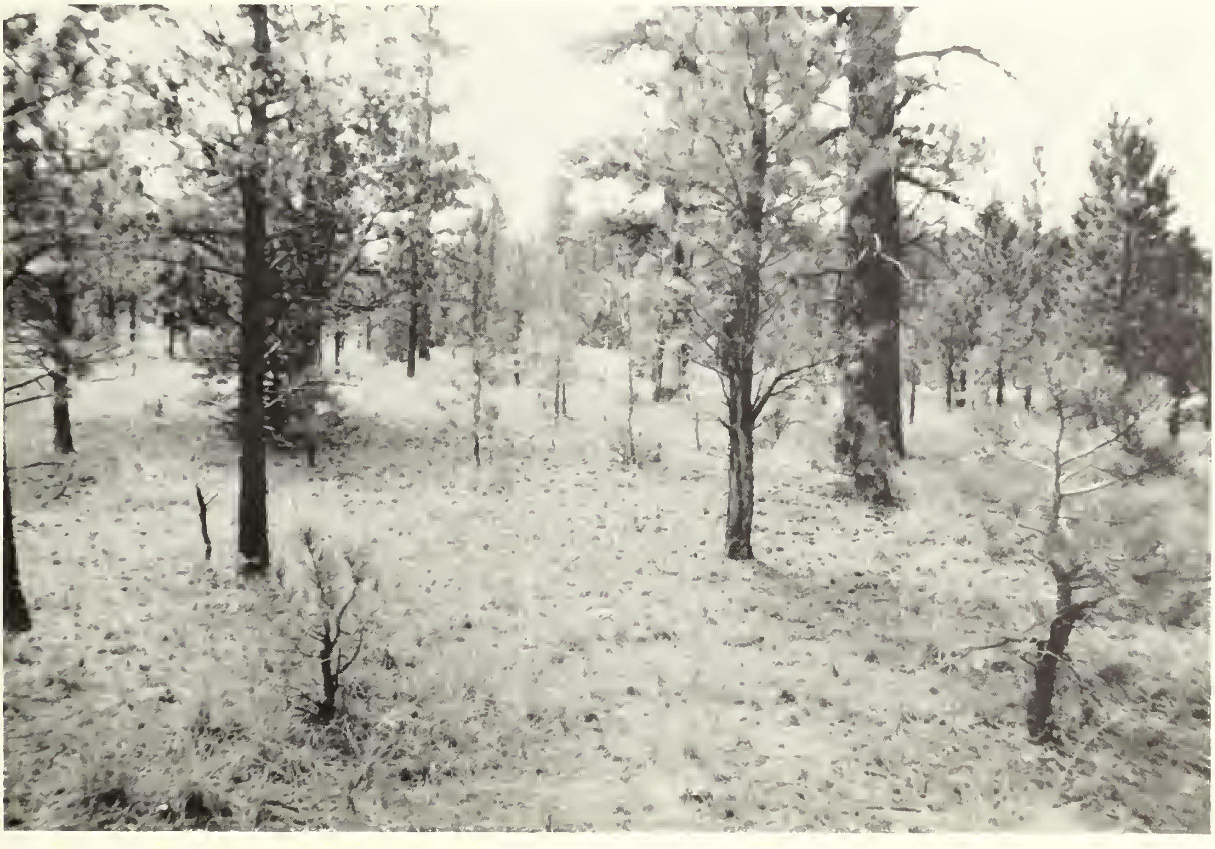
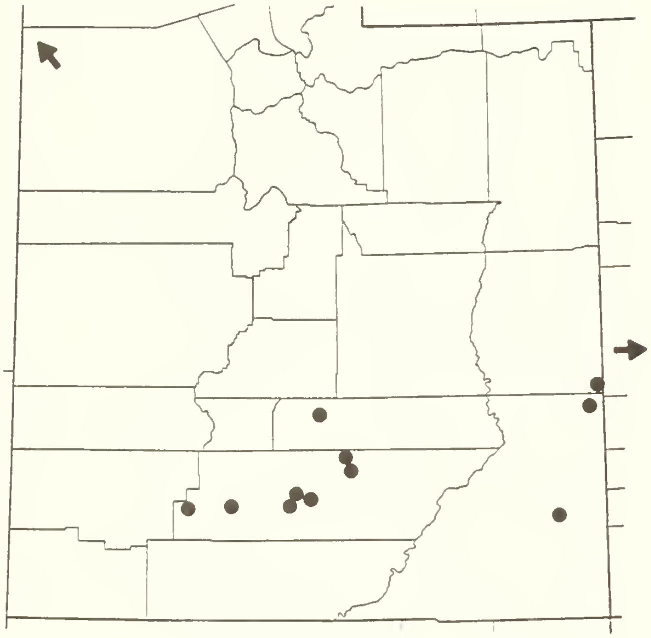


Figure 16.—*Pinus ponderosa/Artemisia nova* h.t. on a northwest bench east of Widtsoe, UT (8,050 feet, 2 450 m). Scattered *Artemisia nova* and *Elymus salina* constitute the undergrowth.

Pinus ponderosa/Purshia tridentata h.t. (PIPO/PUTR; Ponderosa Pine/Bitterbrush)



Distribution.—PIPO/PUTR is a major h.t. within the southern portion of the study area and was observed from the Markagunt Plateau east to the LaSal and Abajo Mountains. It also extends into Colorado (refer to "Other studies"). It occupies gentle to moderate midslopes and benches between 7,100 and 9,000 feet (2 160 and 2 740 m) on a variety of aspects but is more common above 8,000 feet (2 440 m) on southeastern to southwestern slopes. It represents middle to upper elevation sites within the *Pinus ponderosa* series and may often be found above the warmer PIPO/QUGA or PIPO/ARPA h.t.'s. Cooler, more moist sites are often within the ABCO/BERE, PSME/BERE, PSME/SYOR, PIPU/JUCO, or *Abies lasiocarpa* series of h.t.'s. To a limited degree, PIPO/PUTR may indicate areas where cooler air accumulates.

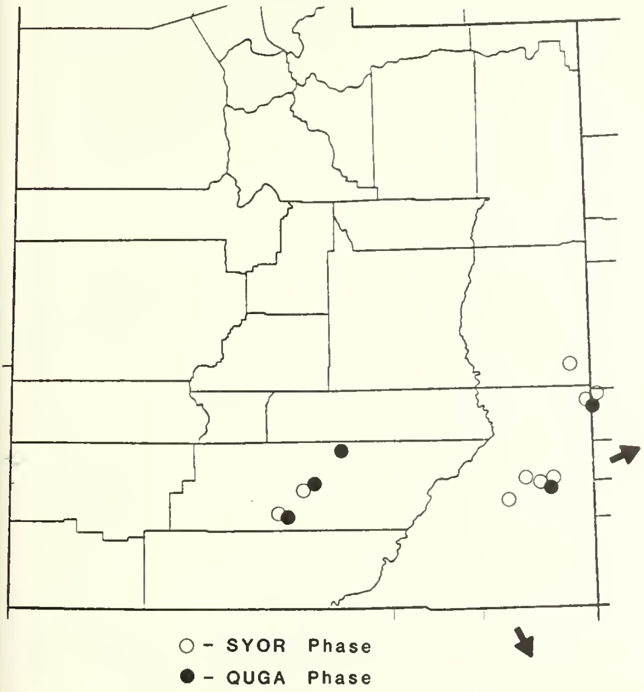
Vegetation.—*Pinus ponderosa* is the dominant conifer, although *Juniperus scopulorum* and *Pinus edulis* may occasionally be present. *Pinus flexilis* and *Pseudotsuga menziesii* can be found as accidentals but usually represent ecotones with adjacent types. *Quercus gambelii* will sometimes be a codominant with *Purshia tridentata* in a light and broken shrub stratum. Other common shrubs include *Artemisia tridentata* (probably ssp. *vaseyana*), *Berberis repens*, and *Symphoricarpos oreophilus*. The herbaceous stratum is also light and diverse and includes small amounts of *Agropyron spicatum*, *Carex rossii*, *Muhlenbergia montana*, *Poa fendleriana*, *Stipa comata*, *Eriogonum racemosa*, and *Hymenoxys richardsonii*. Density and cover of *Purshia* and *Artemisia* within this type may be closely tied to recent disturbances and overstory canopy closures. Sites with *Purshia* present only in full sunlight may represent seral conditions of other h.t.'s such as PIPO/ARPA, PIPO/QUGA, or other series (Harper and Buchanan 1983).

Soils.—PIPO/PUTR usually occurs in colluvium or residual material derived from basalt or sometimes in Jurassic sandstone in the LaSal and Abajo Mountains (appendix F). Many of the sites in the Boulder Mountains have 10 to 35 percent of the surface in bare rock. Amounts of bare soil are relatively low, with litter accumulations averaging 1.3 inches (3.2 cm). Most sites have some coarse fragments in the subsurface horizons including gravels, stones, and cobbles. Surface textures range from sandy loam to silt loam (appendix G).

Productivity/management.—Timber potentials for the PIPO/PUTR h.t. are generally very low (appendix D). *Pinus ponderosa* can be featured by even-aged management and by small clearcut and small group selection systems. Stocking reductions may be necessary for areas in the Boulder Mountains because of rockiness. Most sample sites contained little or no evidence of past natural fires, although fire is certainly an important factor in *Pinus ponderosa* and *Purshia tridentata* ecology (Crane 1982; Lotan and others 1981; Weaver 1968; Martin and Driver 1983). Although most sites show evidence of past grazing, domestic livestock will find little forage here. Wildlife, especially deer, may seek these sites during the summer for available browse.

Other studies.—PIPO/PUTR h.t., a major type in the Western United States, has been described from eastern Washington and Oregon and northern Idaho (Franklin and Dyrness 1973; Hall 1973; Daubenmire and Daubenmire 1968). PIPO/PUTR in southern Utah is similar to the PIPO/PUTR, *Agropyron spicatum* phase described for Montana (Pfister and others 1977) and central Idaho (Steele and others 1981). The difference is that our sites are generally less productive, especially the herbaceous stratum. In Colorado, Hess (1981) found the PIPO/PUTR h.t. on the northern portion of the Roosevelt National Forest.

Pinus ponderosa/Quercus gambelii h.t. (PIPO/QUGA; Ponderosa Pine/ Gambel Oak)



Distribution.—PIPO/QUGA is a major h.t. within the *Pinus ponderosa* series and accounts for large areas within southeastern Utah. It also extends into Colorado and New Mexico (refer to "Other studies"). It occurs on gentle lower to midelevation slopes and benches throughout eastern portions of the Abajo and LaSal Mountains and lower slopes of the Aquarius Plateau. Sites range from 7,300 to 8,800 feet (2 230 to 2 680 m) in elevation and occur on all aspects, with slight differences as noted by phases below. In general, PIPO/QUGA represents the lowest elevation forested site where it occurs. It may gradually intergrade with *Quercus* woodland or, with breaks in topography, it may exist immediately above sandstone cliffs and talus. Drier southwest slopes and ridges may belong to PIPO/ARPA. Cooler sites on benches and more moist aspects are often PIPO/PUTR.

Vegetation.—*Pinus ponderosa* is the dominant conifer on most sites, although *Juniperus scopulorum* may be present as scattered individuals. Mature overstories of *Pinus ponderosa* are relatively dense. The undergrowth is conspicuously shrubby with differences noted by two phases.

Symphoricarpos oreophilus (SYOR) phase: This phase represents the cooler portions of the h.t. occurring at upper elevations and on more northern aspects. On some sites, *Populus tremuloides* may be an early seral associate. In addition to the diagnostic *Quercus gambelii*, which may assume a treelike appearance (fig. 17), and

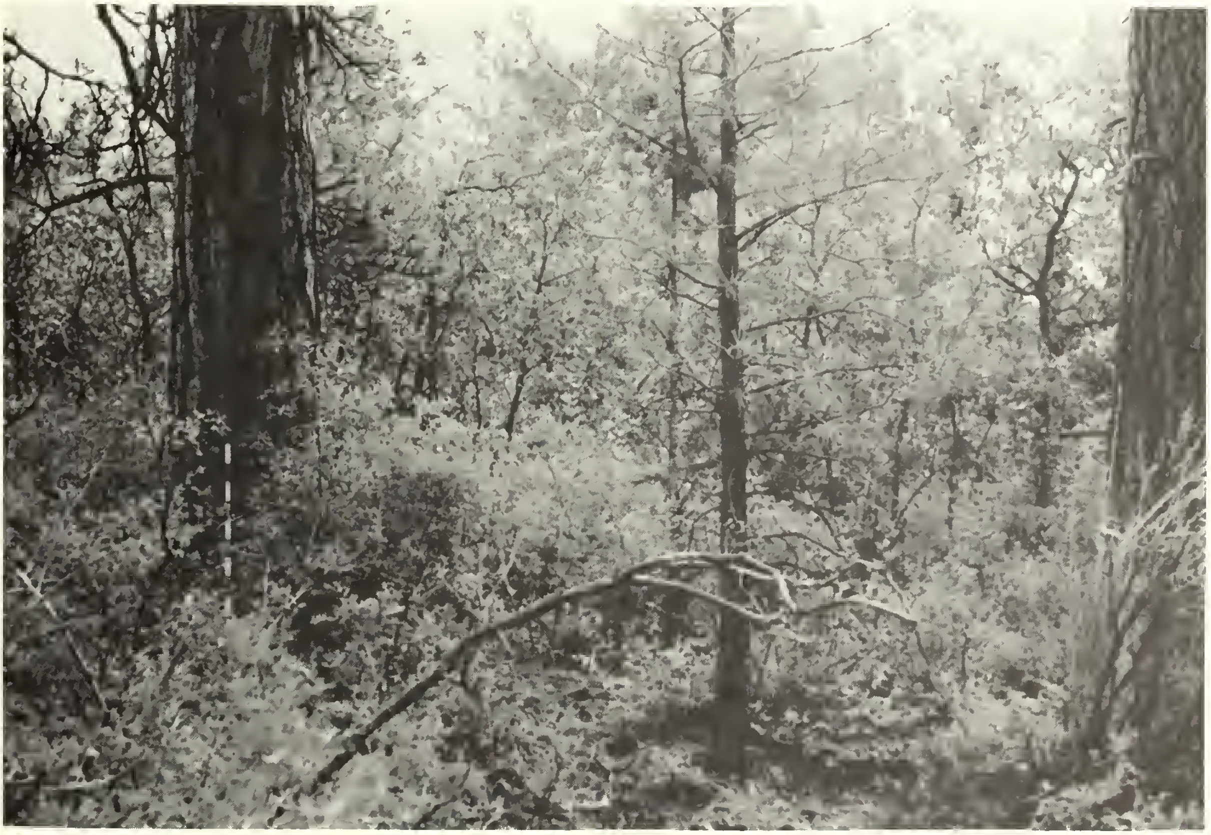


Figure 17.—*Pinus ponderosa/Quercus gambelii* h.t., *Symphoricarpos oreophilus* phase on a gentle southern slope (7,440 feet, 2 270 m) near Hells Backbone on the Aquarius Plateau, north of Escalante, UT. *Pinus ponderosa* and scattered *Juniperus scopulorum* create the overstory. *Pinus ponderosa* is also present as saplings. The shrubby undergrowth consists of *Quercus gambelii*, *Symphoricarpos oreophilus*, and *Rosa woodsii*.

Symphoricarpos oreophilus, the shrub stratum consists of *Amelanchier alnifolia*, *Berberis repens*, and *Rosa woodsii*. *Carex geyeri* may sometimes dominate a diverse and often depauperate herbaceous stratum that includes *Carex rossii*, *Koeleria nitida*, *Poa fendleriana*, and *Wyethia amplexicaulis*. *Hymenoxys richardsonii*, present in all other *Pinus ponderosa* h.t.'s, is absent. This phase represents conditions with the highest structural diversity within the *Pinus ponderosa* series.

Quercus gambelii (QUGA) phase: This phase represents the slightly warmer portions of the h.t., appearing more commonly on eastern aspects at lower elevations. *Quercus gambelii* is usually the dominant shrub in mature undergrowth and rarely achieves the treelike stature noted above (fig. 18). In addition, *Symphoricarpos oreophilus* is not present. *Pinus edulis*, *Juniperus osteosperma*, and *Artemisia tridentata* ssp. *vaseyana* may occur as scattered individuals. Other species are common to the SYOR phase.

Soils.—PIPO/QUGA is most common on Cretaceous and Jurassic sandstone that has weathered in place, but it also occurs on basalt and andesitic flows (appendix F). Surface textures range from sandy loam common in the QUGA phase to loam and silt loam in the SYOR phase (appendix G). Both phases contain normally small amounts of bare soil and exposed rock. Litter accumulations average 1.9 inches (4.9 cm) on undisturbed sites.

Productivity/management.—Timber potentials for the PIPO/QUGA h.t. range from very low to low but are relatively high for the series (appendixes D and E). Site index of *Pinus ponderosa* is only moderately high, but stands usually can be fully stocked. Most ground disturbances associated with timber management, such as burning and scarification, will stimulate *Quercus gambelii* suckering. Because of the structural diversity, these sites also have potentially high wildlife values, especially for birds. Deer may also make use of the browse and mast. Steinhoff (1978), working in southwestern Colorado, found a similar *Pinus ponderosa* and *Quercus gambelii* plant association and listed a number of wildlife species dependent upon this type, including passerine birds and turkeys. Presumably similar relationships would apply for this study area. Effects of natural fire are discussed by Crane (1982). Natural fire frequencies appear to range from 3 to 20 years (Steinhoff 1978, Dieterich 1980, Madany and West 1980). The successional status and problems associated with attempts to control *Q. gambelii* will normally prevent the conversion of shrub to graminoid-dominated undergrowths more suited to livestock (Engle and others 1983).

Other studies.—PIPO/QUGA is a major type south and east of this study area. Similar conditions have been described for the San Juan National Forest in Colorado (Terwilliger and others 1979) where *Symphoricarpos*

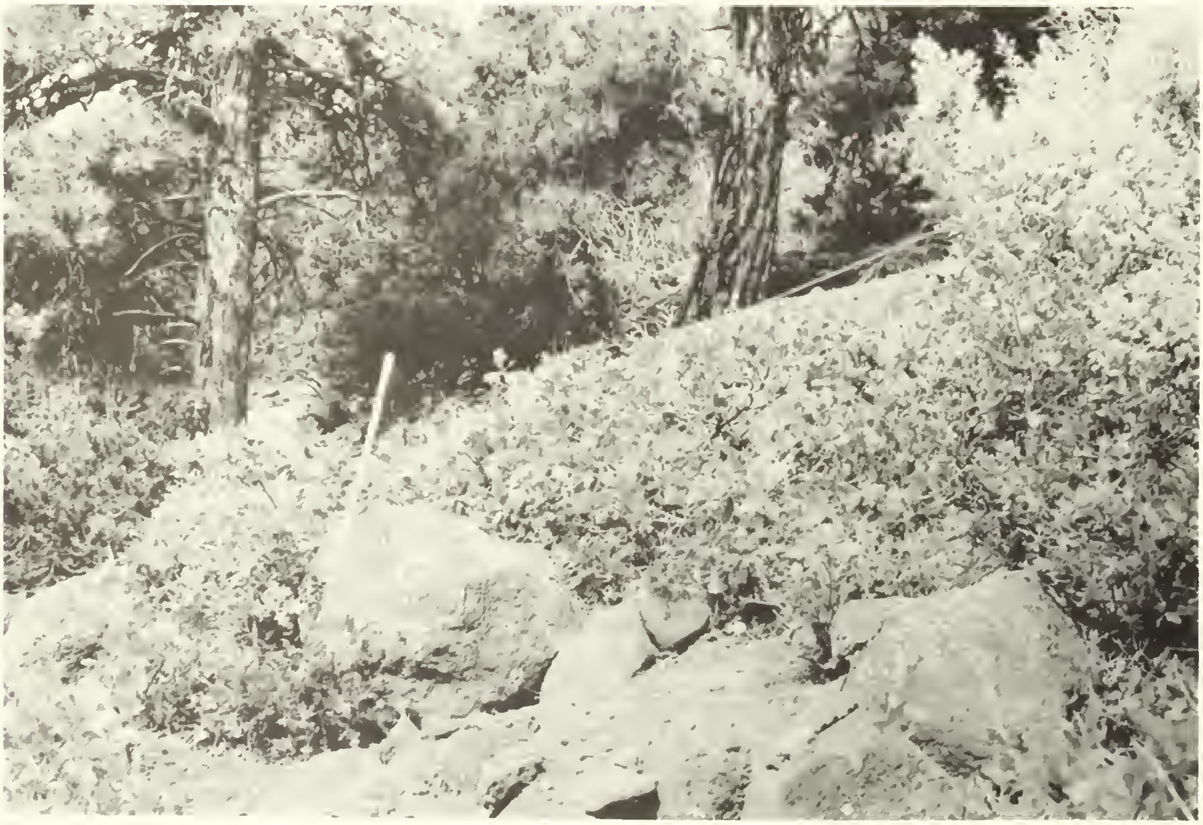
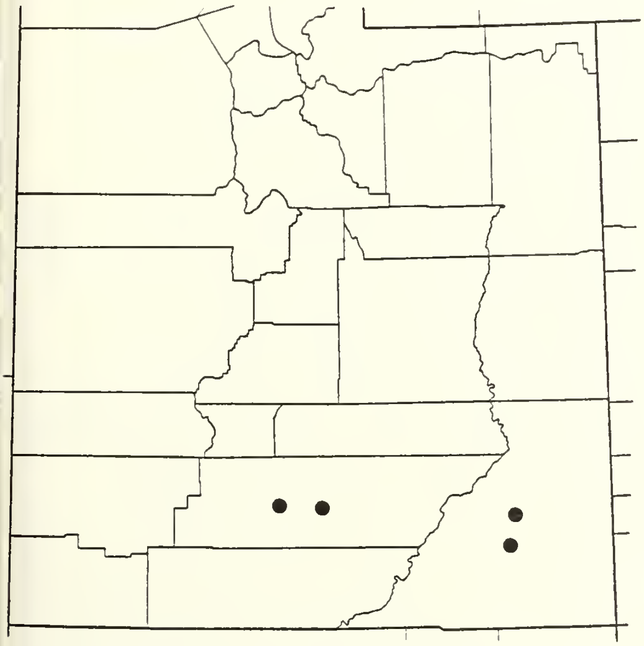


Figure 18.—*Pinus ponderosa/Quercus gambelii* h.t., *Quercus gambelii* phase on a steep southern aspect (8,390 feet, 2 560 m) near Wildcat Pasture in the Boulder Mountains. *Pinus ponderosa* is the dominant conifer, with small amounts of *Pinus edulis* and *Juniperus scopulorum* also present. The undergrowth consists of *Quercus gambelii* and *Shepherdia rotundifolia*.

oreophilus and *Berberis repens* phases exist. The type has also been described from central Colorado, where *Carex geyeri* is a conspicuous dominant in what resembles our SYOR phase (Hess and Wasser 1982). Although the same name is used in New Mexico and Arizona (Hanks and others 1983), the presence of *Festuca arizonica* probably represents differences significant enough to warrant distinction. Three phases, also based upon presence or absence of *F. arizonica* and *Pinus edulis*, have been described for northern New Mexico and southern Colorado (DeVelice and others in press); their *Q. gambelii* phase resembles the SYOR phase of this study.

Pinus ponderosa/Symphoricarpos oreophilus h.t. (PIPO/SYOR; Ponderosa Pine/Mountain Snowberry)



Distribution.—PIPO/SYOR is a minor h.t. within the *Pinus ponderosa* series and appears to be locally common only on the Aquarius Plateau and in the Abajo Mountains. It occurs on gentle to moderate middle slopes with southeastern or western exposures. Elevations range from 7,900 to 8,800 feet (2 410 to 2 680 m) but are most commonly above 8,400 feet (2 560 m). It may abut a variety of dry h.t.'s within the same series, including PIPO/PUTR, PIPO/MUMO, or PIPO/QUGA, or share a boundary with the low elevation, warm and dry extreme of PSME/SYOR or ABCO/SYOR.

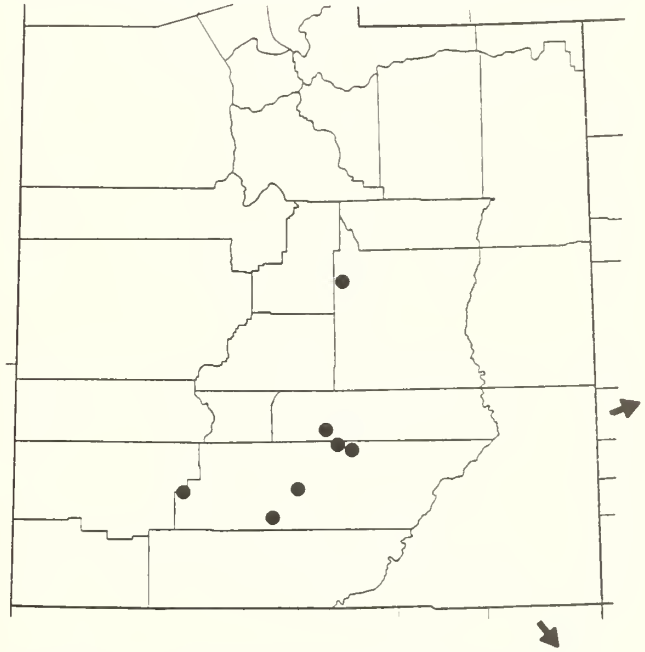
Vegetation.—Mature stands are relatively dense with pure *Pinus ponderosa*. *Juniperus scopulorum* and *Populus tremuloides* may be present in trace amounts as seral associates. *Pseudotsuga menziesii* or *Abies concolor* are accidental. A low conspicuous shrub layer dominates the undergrowth, consisting of *Symphoricarpos oreophilus* and usually *Berberis repens*. Sometimes small amounts of *Amelanchier alnifolia*, *Purshia tridentata*, *Rosa woodsii*, and *Xanthocephalum sarothrae* may also be present. Graminoids also present in small amounts include *Carex rossii*, *Koeleria nitida*, and *Muhlenbergia montana*. The forb component is characteristically absent.

Soils.—Parent materials depend upon locality, with Abajo Mountain sites on Triassic sandstone and Aquarius Plateau sites on basalt or andesite flows (appendix F). Colluvial or residual material is most common, and surface textures are sandy loam to silt loam. Most sites have small amounts of bare soils and exposed rock; one site on the Aquarius Plateau had 35 percent rock. Litter accumulations average 1.8 inches (4.6 cm).

Productivity/management.—Timber potentials are generally low for the h.t. but are relatively high for the series (appendixes D and E). Yields are similar to PIPO/QUGA. Gentle slopes on the Aquarius Plateau present few problems for timber management if small clearcuts, shelterwood, or group selection methods are considered. Steeper slopes in the Abajo Mountains may increase transportation costs. Wildlife features are similar to PIPO/MUMO. Domestic livestock may find moderate forage on these sites.

Other studies.—Steele and others (1981) describe a PIPO/SYOR h.t. from southern Idaho occurring on basalt and granitic parent material. Although associated vegetation and some site characteristics appear similar, overall productivity of our PIPO/SYOR appears to be much higher. This Utah variant of PIPO/SYOR should thus be considered unique.

Pinus ponderosa/Muhlenbergia montana h.t. (PIPO/MUMO; Ponderosa Pine/Mountain Muhly)



Distribution.—PIPO/MUMO is locally common in the southern portion of the study area and was also observed as far north as the Joes Valley portion of the Wasatch Plateau. It occupies dry, low to midelevation portions of the *Pinus ponderosa* series and ranges from 7,100 to 8,800 feet (2 160 to 2 680 m) in elevation on predominantly southern exposures. Slopes range from gentle to steep and are usually convex or straight. PIPO/MUMO may share boundaries with PIPO/SYOR or PIPO/PUTR and occasionally PIPO/QUGA.

Vegetation.—Mature uneven-aged stands of *Pinus ponderosa* are characteristically open and relatively parklike. *Juniperus scopulorum* may be found as a persistent seral associate. All other trees, including *Pinus flexilis, Pseudotsuga menziesii, Juniperus osteosperma*, or *Populus tremuloides*, are considered accidental. PIPO/MUMO represents the most depauperate undergrowths within the *Pinus ponderosa* series, averaging only about 18 percent canopy cover. The shrub stratum is noticeably absent except for scattered *Artemesia tridentata*. Other shrubs that may be present in trace amounts include *Purshia tridentata, Ribes cereum, Symphoricarpos oreophilus*, and *Xanthocephalum sarothrae*. A light but conspicuous graminoid layer consists of *Bouteloua gracilis, Carex rossii, Muhlenbergia montana*, and *Oryzopsis hymenoides*. Graminoids such as *Poa fendleriana* and *Sitanion hystrix* may have increased as other, more palatable, species have been grazed. Forbs are conspicuously absent; only *Hymenoxys richardsonii* and *Erigonum racemosa* have high constancy with trace amounts of cover.

Productivity/management.—Timber potentials are very low (appendix D). Stocking limitations and low site index on some sites will reduce expected yields. Competition from undergrowth species, primarily graminoids, may affect artificial or natural regeneration. The dwarf mistletoe *Arceuthobium vaginatum* ssp. *cryptopodum* may present management concerns. In Colorado, Merrill (1983) showed it to have the potential for higher severity on warm dry sites. Although evidence of fire was not noted for all stands, this h.t. most likely has a relatively high natural fire interval with a surface fire burning every 3 to 10 years carried by the graminoid-dominated undergrowth. Wildlife may find both forage and cover within this type. Turkey habitat may be a key concern because of high visibility within the open parklike undergrowth. Graminoid species may host grasshopper populations. Most stands contain evidence of deer use. Small brush piles, retained during timber harvesting, may benefit turkeys and many species of small mammals by increasing cover.

Other studies.—PIPO/MUMO is a more common type south and east of our study area. It occurs in the San Juan Mountains of southern Colorado and northern New Mexico (DeVelice and others in press) and is scattered throughout central Colorado (Terwilliger and others 1979; Hess 1981). These authors note its development on shallow soils derived from granitic parent material. Our PIPO/MUMO also corresponds to the most mesic portions of *Pinus ponderosa/Bouteloua gracilis* h.t. described from northern Arizona (Hanks and others 1983) and New Mexico (DeVelice and others in press).

Unclassified Stands

Several sample stands throughout the study area are dominated by *Populus tremuloides*. Although sufficient conifer regeneration exists, permitting a determination of the potential climax overstory, undergrowth composition does not allow full h.t. classification. These stands often contain species indicative of heavy grazing. Several stands on the Wasatch Plateau have mature canopies of *Abies lasiocarpa* and *Picea engelmannii* and undergrowth that is excessively depauperate. These stands are often close to stands easily classified into the ABLA/BEREPIEN h.t. One stand contains *Sambucus racemosa* as the dominant undergrowth species. One *Picea pungens* stand in the Boulder Mountains is in an apparent ecotone; the stream bottom site supports *Ribes lacustre, Salix*, and a variety of species common in PIPU/BERE. Four stands dominated by *Picea englemannii* are not classified. Again, most resemble stands belonging to ABLA/BERE, and two are adjacent to *Abies lasiocarpa* sites. One stand on the Paunsaugunt Plateau apparently contains *Ribes lacustre* instead of *Ribes montigenum*; other features are similar to those of the PIEN/RIMO h.t. Many of the unclassified stands would probably belong to the *Pinus ponderosa* series. Several stands contain significant amounts of *Poa fendleriana* and *Sitanion hystrix* and are assumed to be disturbed enough by grazing to warrant exclusion.

INDIVIDUAL ATTRIBUTES OF HABITAT TYPES

Our study concentrated on the following habitat type attributes: the ecological role of plant species, the timber productivity, soils, climate, wildlife habitat values, and the zonal relationships of habitat types.

Ecological Role of Plant Species

The functional role of a plant species often changes within different portions of its environment distribution. This is most easily seen in some of the tree species found in our study area. A given species, such as *Pseudotsuga menziesii*, can be either dominant, codominant, or subordinate, and either climax or seral, depending upon the environmental conditions. Factors that affect its role also determine the associated species' role. Thus, environmental conditions of a site might be ideal for growth and reproduction of *Pseudotsuga*, and also adequate for *Abies lasiocarpa*, which will outcompete *Pseudotsuga*. The functional role of a species depends upon its own environmental amplitude as well as the relative amplitude of its competitors.

The occurrence and role of tree species reflects the relative amplitude and successional status of the species within our study area. Appendix B may provide the user with a number of ecological insights into the classification and its application on the ground. For example, the relative importance of *Populus tremuloides* in all but the *Pinus ponderosa* series is readily apparent. Resource managers may find many situations where consideration of the role and function of *P. tremuloides* is warranted. *Populus tremuloides* may serve as a nurse crop for conifer establishment, as a key wildlife habitat component, or as an important element in revegetation prescriptions. The user is advised to consult a more detailed classification of the *P. tremuloides* ecosystem by Mueggler and Campbell (in prep.) for additional management implications and recommendations. Appendix B also indicates the h.t.'s in which a species is climax, seral, or absent. In general, a seral species is usually selected to favor in timber management because it is easier to regenerate and has higher productivity. The h.t.'s that present opportunities for timber management favoring *Picea engelmannii* are easily determined. More importantly, those sites that do not naturally support *P. engelmannii* can be identified and avoided.

The constancy and average cover data (appendix C) portray the wide diversity between h.t.'s of our study area. The relative amplitude of major forest species, along with the relative importance throughout the complete environmental distribution, is also readily apparent. For example, *Berberis repens* has a wide amplitude, occurring in 29 h.t.'s. However, it is only a relatively important component in the undergrowth of three h.t.'s. Comparisons between h.t.'s allow the user to make meaningful predictions about the occurrence of given species. A number of these observations are discussed within the text; for example, the apparent negative correlation between *Populus tremuloides* and *Vaccinium myrtillus*. A somewhat similar trend also exists with *P. tremuloides* and *Quercus gambelii*. These tables condense the vegetation component information of each h.t. and reduce the need for lengthy type descriptions.

Timber Productivity

Timber productivity was a principal management implication of this study. Site trees were selected to determine the potential height growth of relatively free-growing trees for most species on the site. Unfortunately, site tree data were not always gathered for every sample stand because of stand characteristics. Also, Pfister's data do not include his site index data, although he did report on means and ranges for his types based upon a few samples (Pfister 1972). As a result, projections for some types are tentative. However, the total number of samples (997 trees on 496 sites) does allow a reasonable comparison of productivity between major h.t.'s as well as within most types. The determination of site index from the height-age data follows the procedures established by Pfister and others (1977) and Steele and others (1983). Criteria used to determine total age, as well as the source of site index curve and yield capability data, depend upon the tree species.

For *Picea engelmannii*, *Abies lasiocarpa*, and *Picea pungens*, Alexander's (1967) curves for *P. engelmannii* were used, with a 50-year base for site index. These curves were based on age at breast-height. Yield capabilities were calculated following a procedure developed by Pfister (1977) and Alexander and others (1975), with yield capability = −26.0 + 1.84 site index (50). Similar application of Alexander's work in northern Utah (Mauk and Henderson 1984), central Idaho (Steele and others 1981), and eastern Idaho and western Wyoming (Steele and others 1983) allows comparisons of yield and site index for similar h.t.'s of different areas within the middle and northern Rockies.

For a similar group of species, including *Pseudotsuga menziesii*, *Abies concolor*, and *Pinus flexilis*, the site index curves of Lynch (1958) for *Pinus ponderosa* were used. A 15-year estimate of breast-height age was added to the sampled age of *P. menziesii* and *A. concolor*, while *P. flexilis* ages were increased by 20 years. Yield capability estimates are based upon work by Brickell (1970). Again, this procedure allows for comparisons between the species that commonly grow together, and for comparisons with reported data from outside our study area.

Finally, *Pinus ponderosa* stands were treated somewhat differently. Although Lynch's (1958) site index curves were used with 15-year breast-height age corrections, field observations and comparisons with estimates of yield based upon Brickell's (1970) work for *P. ponderosa* suggested a significant difference between *P. ponderosa* stands in our study area and both southwestern and Inland Empire stands. In general, *P. ponderosa* in central and especially southern Utah appear to maintain diameter growth after a relatively early cessation of height growth. The result is a short, thick bole with a more cylindrical rather than conical shape. Therefore, projected yields based upon available site index and yield capability relationships were underestimated. The most appropriate solution appeared to be the use of Stage's (1973, 1975) stand growth model prognosis. Total standing volume for each sample stand containing *P. ponderosa* was calculated using a Utah variant of the model developed by the Forest Service's Intermountain Region.

Our best estimate of timber productivity is presented in appendixes D and E. Mean basal area and site index by species within each h.t. (appendix D) allow for comparisons by species. This table, combined with appendix B, form much of the basis for recommendation on the most silviculturally appropriate species to favor by management. However, site index alone may not adequately express productivity within a given h.t. Estimated net yield capability (cubic feet), based upon mature and natural stands, is often more useful. As stated by Brickell (1970) and used by Steele and others (1981, 1983) and Mauk and Henderson (1984): "Yield capability, as used by Forest Survey, is defined as mean annual increment of growing stock attainable in fully stocked natural stands at the age of culmination of mean annual increment." Yield capability therefore is the maximum mean annual increment attainable under the constraint of stands being fully stocked and natural. Current estimates of yield capability (in cubic feet/acre/year) for most types are presented in appendix E.

Soils

Characteristics of the upper 3.9 inches (10 cm) of the soil and the surficial geology are summarized in appendix F. Soil sampling throughout the fieldwork leading to this classification was designed to allow simple and preliminary characterization of the surface soils for each h.t. rather than detailed soil-vegetation investigations. However, a number of apparent relationships are suggested by the limited data available. Many h.t.'s within our study area are restricted to particular substrates. These trends are discussed within either the series or h.t. descriptions. Of particular interest is the predominance of major, widespread types, such as ABLA/BERE, ABCO/BERE, PSME/BERE, ABCO/ARPA, and PIPO/ARPA, on sedimentary substrates, especially Tertiary limestone and sandstone. In contrast, ABLA/JUCO, ABLA/CARO, PIEN/RIMO, PSME/SYOR, and PIPO/PUTR are more common on igneous parent materials.

Surface textures for major h.t.'s are arranged along a hypothesized gradient of coarse to fine in appendix G. Although these data are for limited sample sizes and are not intended to replace site-specific soil surveys, they do allow a generalized concept of site conditions for most types. A few h.t.'s with wide geographical distribution, such as ABLA/RIMO-RIMO or ABLA/BERE, also have a relatively wide amplitude in surface textures. Types with fluvial or alluvial depositions have relatively fine textures. Generally, h.t.'s named after the presence of *Berberis repens*, such as ABLA/BERE, PSME/BERE, or ABCO/BERE, tend to have relatively fine surface textures. In contrast, coarser textures are found on types named after *Symphoricarpos oreophilus* or *Juniperus communis*.

Climate

Generalized climatic factors for several weather stations within or adjacent to major h.t.'s are displayed in appendix H, following the graphical representation suggested by Walter (1973). Although many h.t.'s are expected to contain wide variation in annual temperature and precipitation, the overall pattern should be relatively consistent. Interpretation of exact climatic patterns for many h.t.'s is complicated by the effects of soils, topography, and wind.

Wildlife Habitat Values

Although the fieldwork methodology was not designed to determine h.t.-wildlife species relationships, noteworthy observations are included in the specific h.t. descriptions. In general, wildlife may be responding more to the structural characteristics of our h.t.'s than to the exact plant species assemblages. If this is true, then the data reported in appendix C, constancy and average cover of major plant species, can be used to develop a relative ranking of wildlife habitat values for any number of wildlife species. The user must remember these data represent mature stands; early seral conditions, which may be important for wildlife, are not included.

Zonal Relationships of Habitat Types

To depict the relative position and topographic relationship of major h.t.'s within the study area, schematic diagrams (figs. 19—27) are presented for representative localities. Habitat types are arranged in ascending order corresponding to elevation and moisture. Only major or dominant types in the area are shown. The restrictive, usually topoedaphic types, such as those found on stream bottoms, alluvial benches, or steep rocky side slopes, are usually omitted. As Steele and others (1983) note, these diagrams are complicated by the difficulty of depicting a three-dimensional landscape or a multidimensional environment with two axes, but the result is still useful in portraying a concept of the h.t. variation for the different geographic areas.

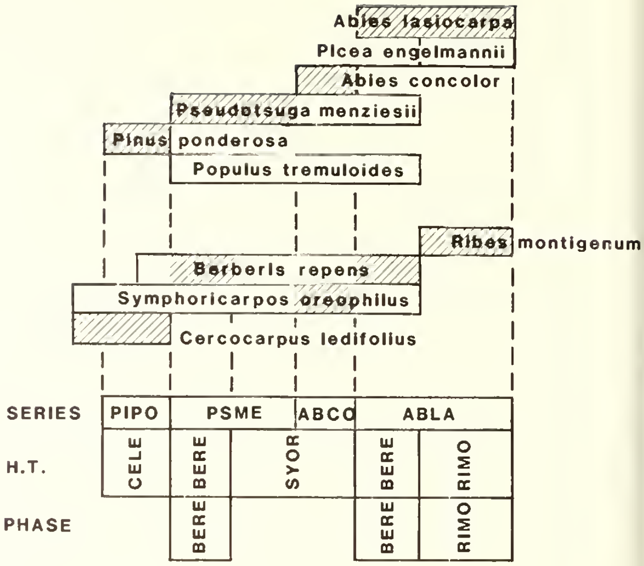


Figure 19.—General relationship of forest vegetation on the Tavaputs Plateau south of Duchesne, UT.

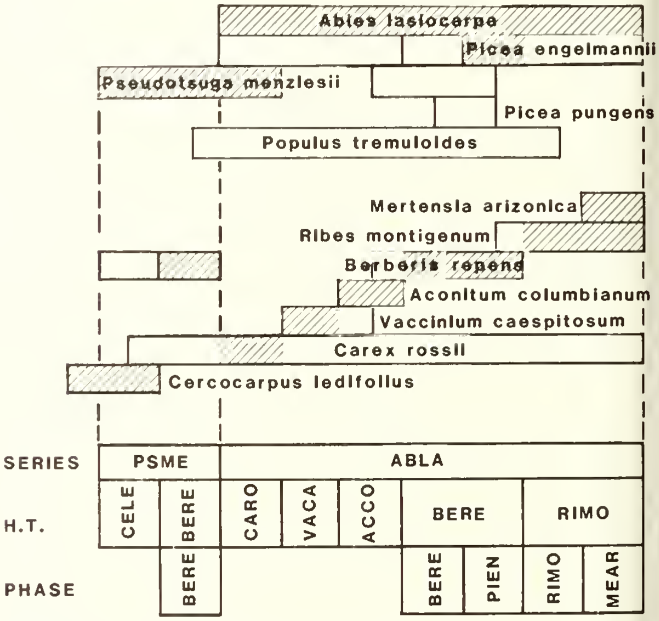


Figure 20.—General relationship of forest vegetation on the Wasatch Plateau near Price, UT.

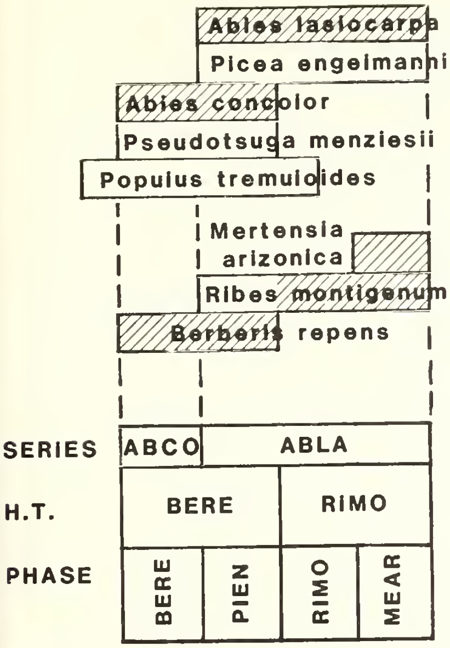


Figure 21.—General relationship of forest vegetation on the Wasatch Plateau near Ephraim, UT.

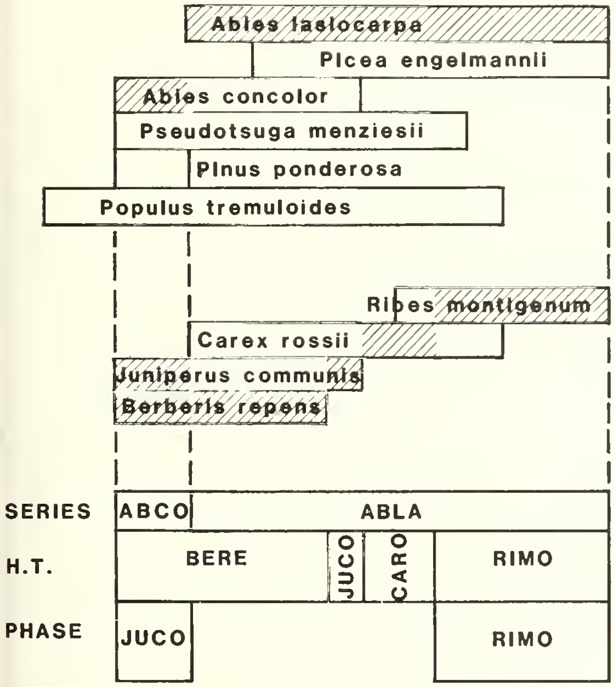


Figure 22.—General relationship of forest vegetation in the Tushar Mountains near Beaver, UT.

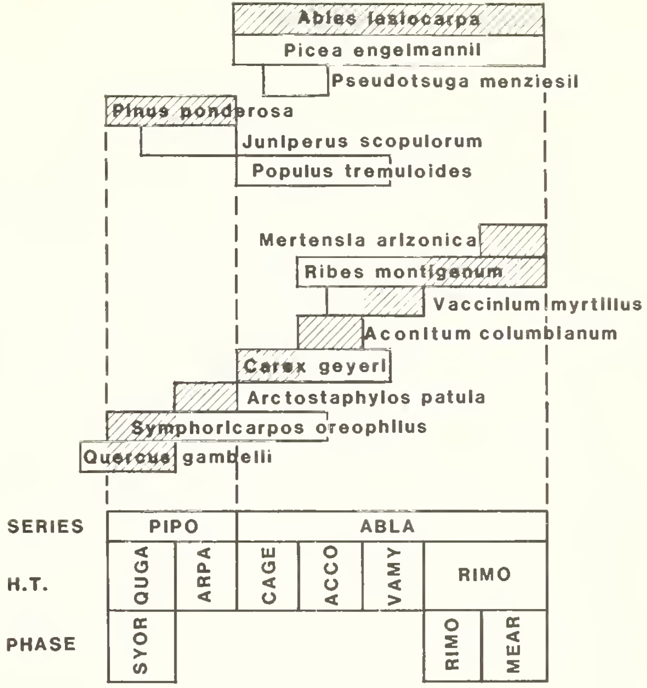


Figure 23.—General relationship of forest vegetation in the LaSal Mountains near Moab, UT.

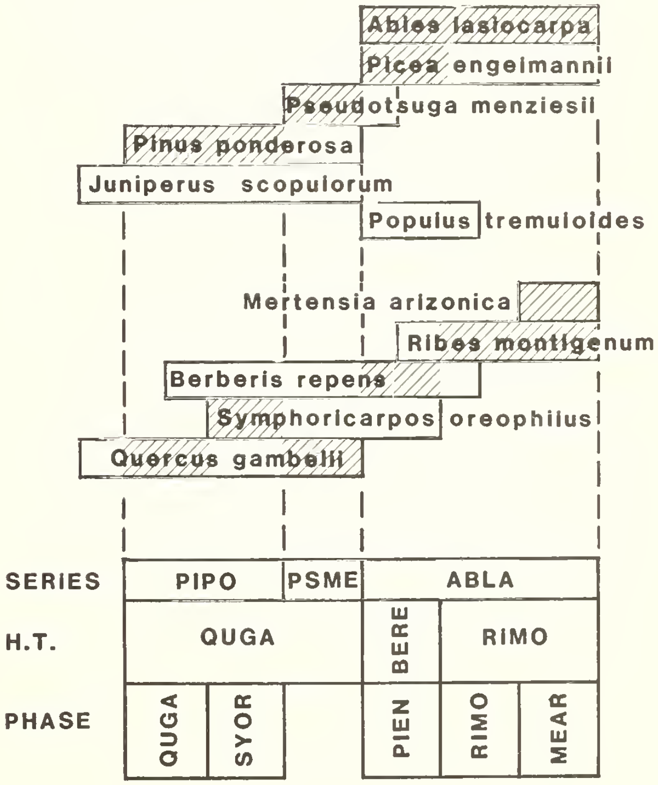


Figure 24.—General relationship of forest vegetation in the Abajo Mountains near Monticello, UT.

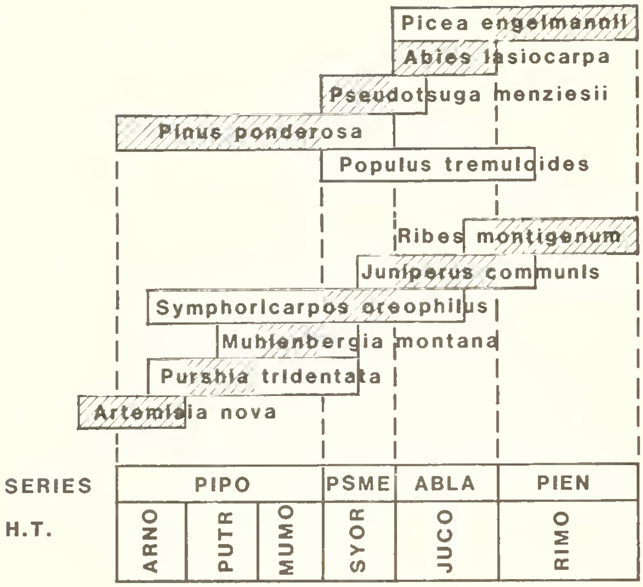


Figure 25.—General relationship of forest vegetation in the Boulder Mountains near Teasdale, UT.

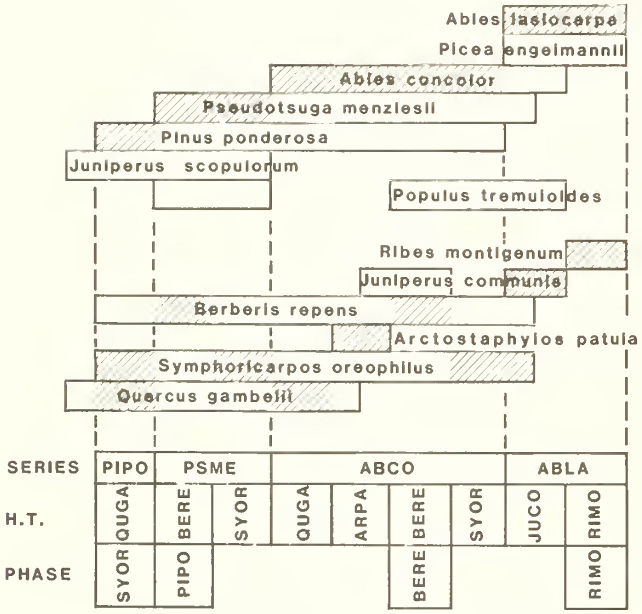


Figure 26.—General relationship of forest vegetation on the Aquarius Plateau north of Escalante, UT.

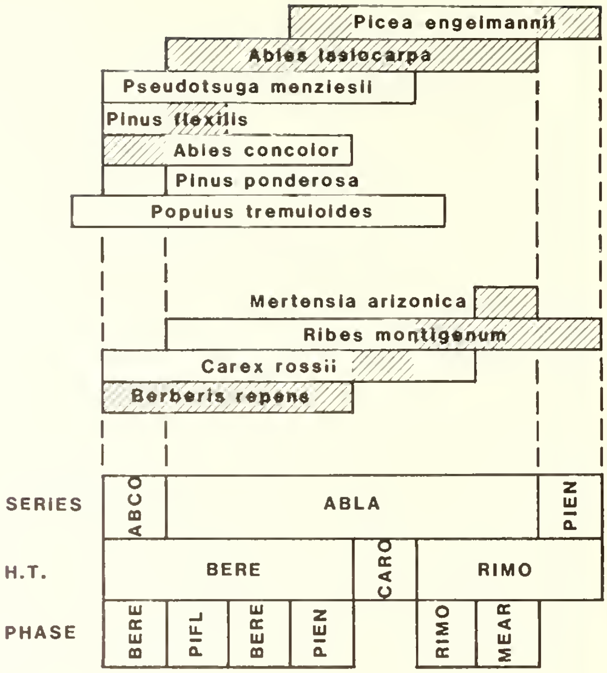


Figure 27.—General relationship of forest vegetation on the Markagunt Plateau near Cedar City, UT.

RELATIONSHIP TO PREVIOUS HABITAT TYPE CLASSIFICATIONS IN THE STUDY AREA

Although much of this classification includes new and previously undescribed h.t.'s, earlier work by Pfister (1972) and Kerr and Henderson (1979) was incorporated. Pfister's treatment of the subalpine forests and Kerr and Henderson's classification for a small test strip of the Wasatch Plateau were considered first approximations and therefore influenced the conceptual development of types reported by the classification. Where appropriate, these relationships are displayed in figure 28. In general, the increase in sample stand numbers over a larger area allowed for the refinement of more h.t.'s representing smaller partitions of the environment. The most notable difference between this work and that reported by Kerr and Henderson (1979) is the standardization of nomenclature for the *Abies lasiocarpa* series. The ABLA/BERE h.t. described by Pfister (1972) has had major revision to incorporate phasal distinctions based upon overstory associations that affect timber management and undergrowth differences that apparently represent significantly different site conditions.

SUBALPINE FOREST (Pfister, 1972)	PRICE DISTRICT (Kerr & Henderson, '79)	CENTRAL & SOUTHERN UTAH
	PIEN-ABLA/RIMO (In part)	ABLA/ACCO
	PIEN-ABLA/VACA	ABLA/VACA,PIEN
	PIEN-ABLA/VAME	ABLA/VAGL
ABLA/BERE,ABLA		ABLA/ACGL
		ABLA/BERE,BERE
ABLA/BERE,RIMO (In part)		ABLA/BERE,PIFL
	PIEN-ABLA/BERE (in part)	ABLA/BERE,PIEN
ABLA/BERE,BERE		ABLA/CAGE
		ABLA/JUCO
ABLA/RIMO,RIMO (In part)	PIEN-ABLA/OSCH PIEN-ABLA/BERE (in part)	ABLA/CARO
ABLA/BERE,RIMO (In part) ABLA/RIMO,RIMO (In part) ABLA/RIMO,THFE	PIEN-ABLA/ARCO ABLA/RIMO	ABLA/RIMO,RIMO
ABLA/RIMO,LOIN	PIEN-ABLA/RIMO (in part)	ABLA/RIMO, MEAR
		ABLA/VAMY
PIEN/RIMO		PIEN/RIMO
	PIPU/BERE	PIPU/BERE
		PIPU/JUCO

Figure 28.—Relationship with previous habitat type classifications in central and southern Utah.

USE OF THE CLASSIFICATION

This classification attempts to provide a natural stratification of the coniferous forest lands in central and southern Utah. The classification is based upon the potential natural vegetation and is designed to reflect the combined effects of the environment upon a given site. An accurate and specific determination of the exact environmental factors affecting each site is thus unwarranted. Indeed, the overall goal of this classification effort is to develop types that are meaningful and useful to the resource manager, who may be more concerned with management practices and their consequences than with ecophysiological requirements and adaptations. Therefore, validation will only come with application. Even though this classification is considered extensive, based upon 12 years of work and over 727 sample stands, additional minor or unique situations may exist and warrant description. Users may forward recommendations for further refinement to the Regional Ecology and Classification Program, Intermountain Region, USDA Forest Service, Ogden, UT.

Pfister (1976) and Steele and others (1983) have outlined potential values of habitat types in resource management. They suggest the most important use is a land stratification system that designates areas of land with approximately equivalent environments or biotic potential. Resource managers should immediately recognize the benefits of incorporating h.t.'s into the long-range planning process. Some other current and potential uses include:

1. Communication - the classification provides a common framework for users with different disciplines and allows for the extrapolation of existing knowledge to new and different sites.
2. Timber management - the classification provides an assessment of relative timber productivity and silvicultural methods.
3. Range and wildlife management - the classification provides a basis for determining wildlife and range values and changes following disturbances.
4. Forest protection - the classification provides a basis for describing relative rates of fuels accumulations, fire effects and the role of natural fire, and the natural susceptibility of forest sites to insects and disease.
5. Natural area preservation and research - the classification indicates the degree of diversity that requires representation within the research natural area system and provides a stratification level in future research study designs.

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APPENDIX A.—NUMBER OF SAMPLE STANDS BY HABITAT TYPE, PHASE, AND VICINITY IN CENTRAL AND SOUTHERN UTAH

PV = Pine Valley Mountains, Dixie National Forest
DP = Markagunt, Paunsaugunt, Sevier, and Aquarius Plateaus, Escalante and Boulder Mountains in the Dixie National Forest
AM = Abajo Mountains, Manti-LaSal National Forest
LM = LaSal Mountains, Manti-LaSal National Forest
FL = Fish Lake Plateau, Tushar, and Pahvant Mountains in the Fishlake National Forest
WP = Wasatch Plateau, Manti-LaSal National Forest
TP = Tavaputs Plateau, Ashley National Forest
CB = Cedar Breaks National Monument
BC = Bryce Canyon National Park

	Vicinity									
Habitat type, phase	PV	DP	AM	LM	FL	WP	TP	CB	BC	Total
Abies lasiocarpa Series										
ABLA/ACCO	1	1	2	3	1	8	·	1	·	17
ABLA/PHMA	·	·	·	·	·	5	·	·	·	5
ABLA/ACGL	1	·	·	1	2	3	·	·	·	7
ABLA/VACA,PIEN	·	·	·	·	·	14	·	·	·	14
ABLA/VAGL	·	·	·	·	·	4	·	·	·	4
ABLA/VAMY	·	·	1	6	·	·	·	·	·	7
ABLA/BERE,PIFL	·	14	·	·	·	2	·	·	·	16
ABLA/BERE,PIEN	·	16	3	2	6	24	·	·	·	51
ABLA/BERE,BERE	·	9	·	2	11	5	3	·	·	30
ABLA/RIMO,MEAR	·	9	4	7	2	9	·	6	·	37
ABLA/RIMO,RIMO	1	25	6	10	17	63	6	·	·	128
ABLA/CAGE	·	·	2	4	·	·	·	·	·	6
ABLA/JUCO	2	14	·	·	8	1	·	·	·	25
ABLA/CARO	1	12	·	·	9	5	·	·	·	27
										374
Abies concolor Series										
ABCO/PHMA	·	·	·	·	2	·	·	·	·	2
ABCO/ACGL	1	·	1	·	1	·	·	·	·	4
ABCO/CELE	3	·	·	·	3	1	1	·	1	9
ABCO/ARPA	1	7	2	·	·	·	·	·	2	12
ABCO/QUGA	·	2	·	·	2	1	·	·	·	7
ABCO/BERE,JUCO	·	5	·	·	3	3	·	·	2	13
ABCO/BERE,BERE	1	12	·	·	3	8	·	·	2	26
ABCO/JUCO	·	3	·	·	2	·	·	·	·	5
ABCO/SYOR	·	5	·	·	·	2	2	·	2	11
										89
Picea engelmannii Series										
PIEN/RIMO	·	18	·	·	2	·	·	·	·	20
										20
Picea pungens Series										
PIPU/EQAR	·	5	·	·	·	·	·	·	·	5
PIPU/JUCO	·	7	·	·	2	3	1	·	·	13
PIPU/BERE	·	5	·	·	1	4	2	·	·	12
										30
Pinus flexilis-Pinus longaeva Series	·	7	·	·	2	6	3	·	·	18
										18

(con.)

APPENDIX A.—(Con.)

	Vicinity									
Habitat type, phase	PV	DP	AM	LM	FL	WP	TP	CB	BC	Total
Pseudotsuga menziesii Series										
PSME/PHMA	•	•	•	1	1	1	•	•	•	3
PSME/CELE	•	2	•	•	1	7	1	•	•	11
PSME/ARPA	•	1	•	•	1	•	•	•	•	5
PSME/CEMO	•	1	•	•	1	1	2	•	3	5
PSME/QUGA	•	2	3	•	•	•	•	•	•	5
PSME/BERE,PIPO	•	7	•	•	1	•	•	•	•	8
PSME/BERE,BERE	•	2	•	1	1	13	4	•	•	21
PSME/SYOR	•	13	•	•	3	1	2	•	•	19
										77
Pinus ponderosa Series										
PIPO/CELE	2	2	•	•	•	•	2	•	•	6
PIPO/ARPA	•	9	•	3	•	•	•	•	3	15
PIPO/ARNO	•	7	•	•	•	•	•	•	1	8
PIPO/PUTR	•	16	1	2	1	•	•	•	1	21
PIPO/QUGA,SYOR	•	3	6	6	•	•	•	•	•	15
PIPO/QUGA,QUGA	•	4	8	2	•	•	•	•	•	14
PIPO/SYOR	•	3	3	•	•	•	•	•	•	6
PIPO/MUMO	•	7	•	•	•	1	•	•	•	8
										93
Unclassified stands	•	16	1	•	•	9	•	•	•	26
										26
Total	14	272	44	50	90	204	29	7	17	727

APPENDIX B.—OCCURRENCE AND SUCCESSIONAL ROLE OF TREE SPECIES BY HABITAT TYPE AND PHASE FOR CENTRAL AND SOUTHERN UTAH

C = major climax species c = minor climax species
S = major seral species s = minor seral species
a = accidental ( ) = only in portions of h.t.

Habitat type, phase	Species											
	JUOS	JUSC	PIED	POTR	PIPO	PSME	PIFL	PILO	PIPU	PIEN	ABCO	ABLA
ABLA/ACCO	·	·	·	(s)	a	(s)	a	·	·	c	(S)	C
ABLA/PHMA	·	·	·	S	·	S	·	·	·	(S)	·	C
ABLA/ACGL	·	·	·	S	·	S	(s)	·	(s)	S	S	C
ABLA/VACA,PIEN	·	·	·	S	·	a	·	·	·	S	a	C
ABLA/VAMY	·	·	·	·	·	a	·	·	·	S	·	C
ABLA/BERE,PIFL	·	·	·	S	a	S	S	a	s	·	(s)	C
ABLA/BERE,PIEN	·	·	·	S	·	(S)	a	·	(s)	S	(s)	C
ABLA/BERE,BERE	·	·	·	S	a	S	a	a	(S)	a	(S)	C
ABLA/RIMO,MERE	·	·	·	(S)	·	a	a	·	·	c	a	C
ABLA/RIMO,RIMO	·	·	·	(S)	·	(s)	a	·	·	c	·	C
ABLA/CAGE	·	·	·	S	·	(s)	·	·	·	S	·	C
ABLA/JUCO	·	·	·	S	·	(s)	(s)	(s)	(s)	S	(s)	C
ABLA/CARO	·	·	·	S	a	S	a	·	a	S	·	C
ABCO/CELE	·	s	·	a	S	S	(s)	·	·	·	C	·
ABCO/ARPA	·	c	·	a	S	S	S	(s)	(s)	·	C	·
ABCO/QUGA	·	c	a	·	S	S	a	·	·	·	C	·
ABCO/BERE,JUCO	·	a	·	S	S	S	s	(s)	S	a	C	·
ABCO/BERE,BERE	·	(s)	·	S	S	S	(s)	(s)	(s)	·	C	a
ABCO/JUCO	·	(s)	·	S	a	s	s	·	S	·	C	a
ABCO/SYOR	·	c	·	(s)	S	S	a	·	a	·	C	·
PIEN/RIMO	·	·	·	(s)	·	·	·	·	·	C	·	a
PIPU/EQAR	·	·	·	S	·	(s)	·	·	C	(c)	·	a
PIPU/JUCO	·	s	·	S	(S)	(s)	(s)	a	C	a	·	a
PIPU/BERE	·	(S)	·	S	S	S	S	a	C	·	·	a
PIFL-PILO	·	(c)	a	(s)	a	(c)	C	(C)	·	a	a	a
PSME/CELE	·	c	(s)	(s)	(s)	C	·	(s)	·	·	a	·
PSME/ARPA	·	c	·	·	S	C	S	·	·	·	·	·
PSME/CEMO	c	c	c	·	a	C	·	·	·	·	a	·
PSME/QUGA	·	c	·	a	S	C	·	·	·	·	a	·
PSME/BERE,PIPO	·	s	·	S	S	C	a	·	·	·	·	a
PSME/BERE,BERE	·	s	·	s	a	C	(s)	·	a	·	·	·
PSME/SYOR	·	c	a	s	S	C	a	·	a	·	·	a
PIPO/CELE	(s)	c	s	·	C	a	·	·	·	·	a	·
PIPO/ARPA	·	c	·	·	C	a	(s)	·	a	a	·	·
PIPO/ARNO	·	c	·	·	C	a	(s)	·	a	a	·	·
PIPO/PUTR	·	c	a	·	C	a	a	·	·	a	·	·
PIPO/QUGA,SYOR	·	s	·	a	C	a	·	·	·	·	·	·
PIPO/QUGA,QUGA	(s)	s	(s)	·	C	a	·	·	·	·	·	·
PIPO/SYOR	·	s	·	(s)	C	a	·	·	·	·	a	a
PIPO/MUMO	a	s	a	a	C	a	a	·	·	·	·	·

APPENDIX C.—CONSTANCY AND AVERAGE COVER (THE LATTER IN PARENTHESES) OF IMPORTANT PLANTS IN CENTRAL AND SOUTHERN UTAH HABITAT TYPES AND PHASES

	ABLA/ ACCO	ABLA/ PHMA	ABLA/ ACGL	ABLA/ VACA PIEN	ABLA/ VAMY	ABLA/ BERE PIFL	ABLA/ BERE PIEN	ABLA/ BERE BERE
NO. STANDS IN H.T.	17	5	7	14	7	16	51	30
TREES								
ABIES LASIOCARPA	100(24)	100(45)	100(38)	93(21)	100(29)	100(37)	100(45)	100(57)
ABIES CONCOLOR	6(45)	-(-)	57(22)	7(1)	-(-)	25(17)	2(65)	13(32)
PICEA ENGELMANNII	100(48)	40(40)	86(15)	100(33)	100(76)	56(19)	100(33)	7(1)
PICEA PUNGENS	-(-)	-(-)	14(T)	-(-)	-(-)	31(18)	12(5)	33(30)
PSEUDOTSUGA MENZIESII	12(25)	60(14)	71(43)	7(5)	14(6)	81(33)	43(21)	57(38)
PINUS FLEXILIS	6(12)	-(-)	29(11)	-(-)	-(-)	100(11)	8(1)	7(1)
PINUS LONGAEVA	-(-)	-(-)	-(-)	-(-)	-(-)	13(3)	-(-)	3(T)
PINUS PONDEROSA	6(4)	-(-)	-(-)	-(-)	-(-)	13(6)	-(-)	10(2)
POPULUS TREMULOIDES	41(8)	60(17)	57(13)	57(6)	-(-)	81(22)	71(20)	90(36)
PINUS EDULIS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
JUNIPERUS SCOPULORUM	-(-)	-(-)	14(7)	-(-)	-(-)	-(-)	-(-)	-(-)
JUNIPERUS OSTEOSPERMA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
SHRUBS								
ACER GLABRUM	6(1)	40(8)	100(6)	-(-)	-(-)	-(-)	-(-)	3(T)
AMELANCHIER ALNIFOLIA	18(3)	-(-)	43(2)	-(-)	-(-)	44(1)	12(T)	7(T)
ARCTOSTAPHYLOS PATULA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	3(40)
ARCTOSTAPHYLOS UVA-URSI	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	3(2)
ARTEMISIA NOVA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
ARTEMISIA TRIDENTATA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
BERBERIS REPENS	12(T)	60(1)	71(5)	21(2)	-(-)	100(11)	67(6)	90(7)
CEANOTHUS MARTINII	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
CERCOCARPUS LEDIFOLIUS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
CERCOCARPUS MONTANUS	-(-)	-(-)	14(1)	-(-)	-(-)	-(-)	-(-)	-(-)
CHRYSOTHAMNUS PARRYI	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
CHRYSOTHAMNUS VISCIDIFLORUS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
JUNIPERUS COMMUNIS	6(T)	-(-)	14(T)	7(T)	29(T)	94(9)	39(7)	50(10)
LINNAEA BOREALIS	6(4)	-(-)	-(-)	14(11)	-(-)	-(-)	-(-)	-(-)
LONICERA INVOLUCRATA	29(2)	-(-)	-(-)	-(-)	86(4)	-(-)	4(T)	-(-)
LONICERA UTAHENSIS	12(1)	60(8)	43(7)	14(T)	14(3)	-(-)	22(4)	7(2)
PACHISTIMA MYRSINITES	24(2)	80(3)	86(1)	86(2)	14(1)	63(1)	75(4)	47(3)
PHYSOCARPUS MALVACEUS	-(-)	100(10)	14(4)	-(-)	-(-)	-(-)	2(T)	7(1)
PRUNUS VIRGINIANA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
PURSHIA TRIDENTATA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
QUERCUS GAMBELII	6(T)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
RIBES CEREUM	6(10)	-(-)	-(-)	-(-)	-(-)	38(4)	4(1)	7(10)
RIBES MONTIGENUM	88(6)	40(1)	-(-)	50(1)	100(8)	50(5)	45(5)	7(4)
RIBES VISCOSISSIMUM	-(-)	80(4)	43(11)	21(1)	-(-)	-(-)	10(2)	-(-)
ROSA WOODSII	18(1)	20(T)	57(5)	14(1)	-(-)	63(2)	41(2)	70(3)
SALIX SCOULERIANA	6(T)	-(-)	-(-)	-(-)	-(-)	-(-)	2(8)	-(-)
SAMBUCUS RACEMOSA	41(2)	40(1)	-(-)	14(2)	-(-)	13(1)	16(1)	10(1)
SHEPHERDIA CANADENSIS	6(T)	40(2)	-(-)	29(2)	-(-)	6(T)	14(2)	10(13)
SHEPHERDIA ROTUNDIFOLIA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
SYMPHORICARPOS OREOPHILUS	53(2)	40(1)	86(10)	50(1)	-(-)	88(5)	65(5)	80(6)
VACCINIUM CAESPITOSUM	6(35)	-(-)	-(-)	100(25)	-(-)	-(-)	-(-)	-(-)
VACCINIUM MYRTILLUS	6(35)	-(-)	-(-)	-(-)	100(56)	-(-)	2(2)	-(-)
XANTHOCEPHALUM SAROTHRAE	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)

(con.)

APPENDIX C.—(Con.)

	ABLA/ ACCO	ABLA/ PHMA	ABLA/ ACGL	ABLA/ VACA PIEN	ABLA/ VAMY	ABLA/ BERE PIFL	ABLA/ BERE PIEN	ABLA/ BERE BERE
NO. STANDS IN H.T.	17	5	7	14	7	16	51	30
GRAMINOIDS								
AGROPYRON SPICATUM	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
BOUTELOUA GRACILIS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
BROMUS CARINATUS	12(8)	-(-)	-(-)	-(-)	-(-)	19(1)	-(-)	3(2)
BROMUS CILIATUS	65(1)	-(-)	-(-)	43(1)	71(1)	44(2)	31(3)	47(1)
CAREX DISPERMA	6(1)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
CAREX GEYERI	24(6)	-(-)	14(30)	-(-)	43(4)	6(T)	8(17)	7(15)
CAREX ROSSII	24(1)	40(1)	-(-)	50(2)	14(T)	81(3)	67(1)	77(1)
ELYMUS GLAUCUS	12(2)	-(-)	14(1)	-(-)	-(-)	-(-)	8(1)	3(2)
FESTUCA OVINA	-(-)	-(-)	-(-)	-(-)	-(-)	25(1)	2(T)	3(T)
GLYCERIA ELATA	6(5)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
KOELERIA NITIDA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
MUHLENBERGIA MONTANA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
ORYZOPSIS HYMENOIDES	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
POA	12(2)	-(-)	-(-)	-(-)	29(T)	13(1)	4(T)	3(3)
POA FENDLERIANA	-(-)	-(-)	-(-)	-(-)	-(-)	31(1)	6(3)	17(1)
POA NERVOSA	-(-)	-(-)	-(-)	-(-)	-(-)	19(1)	2(T)	7(T)
POA PRATENSIS	-(-)	-(-)	-(-)	7(2)	-(-)	-(-)	-(-)	7(4)
SITANION HYSTRIX	-(-)	-(-)	-(-)	-(-)	-(-)	44(1)	8(1)	27(1)
STIPA COLUMBIANA	6(T)	-(-)	-(-)	-(-)	-(-)	-(-)	2(T)	7(13)
STIPA COMATA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
STIPA LETTERMANII	-(-)	-(-)	-(-)	7(5)	-(-)	25(2)	6(1)	13(1)
TRISETUM SPICATUM	-(-)	-(-)	-(-)	14(T)	-(-)	13(1)	8(T)	-(-)
FORBS								
ACHILLEA MILLEFOLIUM	35(1)	-(-)	-(-)	14(T)	-(-)	56(1)	20(3)	33(2)
ACONITUM COLUMBIANUM	53(7)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
ACTAEA RUBRA	47(2)	-(-)	14(T)	-(-)	-(-)	-(-)	-(-)	3(T)
AQUILEGIA COERULEA	59(1)	20(1)	14(1)	29(T)	43(1)	31(1)	45(3)	20(1)
ARABIS DRUMMONDII	-(-)	-(-)	-(-)	-(-)	-(-)	13(T)	8(T)	20(T)
ARNICA CORDIFOLIA	47(3)	40(3)	43(1)	50(5)	71(2)	6(2)	37(5)	13(3)
ASTER ENGELMANNII	24(1)	-(-)	-(-)	57(1)	-(-)	6(15)	14(3)	3(1)
ASTRAGALUS MISER	-(-)	-(-)	14(2)	-(-)	-(-)	63(2)	22(2)	27(7)
BALSAMORHIZA SAGITTATA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
DELPHINIUM BARBEYI	12(5)	-(-)	-(-)	-(-)	14(2)	-(-)	4(9)	3(2)
DELPHINIUM OCCIDENTALE	47(12)	-(-)	-(-)	-(-)	-(-)	-(-)	2(1)	-(-)
EPILOBIUM ANGUSTIFOLIUM	29(1)	20(T)	14(2)	36(1)	43(T)	6(T)	25(2)	17(1)
ERIGERON PEREGRINUS	29(3)	-(-)	-(-)	-(-)	43(3)	13(2)	10(4)	10(1)
ERIOGONUM RACEMOSUM	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
GERANIUM RICHARDSONII	76(8)	-(-)	-(-)	7(T)	43(1)	13(8)	-(-)	-(-)
GERANIUM VISCOSISSIMUM	-(-)	-(-)	29(1)	-(-)	-(-)	25(1)	4(1)	10(1)
HAPLOPAPPUS PARRYI	6(T)	-(-)	29(2)	-(-)	-(-)	19(6)	24(5)	20(2)
HELENIUM HOOPESII	12(1)	-(-)	-(-)	14(T)	43(1)	-(-)	16(3)	10(6)
HERACLEUM LANATUM	24(6)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
HYMENOXYS RICHARDSONII	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
LATHYRUS LANSZWERTII	41(2)	20(4)	57(3)	57(2)	71(11)	19(6)	37(8)	23(11)
LATHYRUS PAUCIFLORUS	6(2)	-(-)	-(-)	-(-)	14(1)	-(-)	4(15)	-(-)
LIGUSTICUM PORTERI	35(T)	-(-)	14(T)	-(-)	14(T)	19(1)	8(4)	3(2)
LUPINUS ARGENTEUS	-(-)	-(-)	-(-)	-(-)	-(-)	6(T)	10(2)	20(1)
MERTENSIA ARIZONICA	24(9)	-(-)	-(-)	-(-)	-(-)	13(1)	20(2)	7(1)
MERTENSIA CILIATA	35(9)	-(-)	-(-)	7(T)	29(T)	-(-)	6(1)	3(3)
OSMORHIZA CHILENSIS	82(11)	80(1)	57(4)	86(1)	100(6)	19(5)	67(4)	37(3)
PEDICULARIS RACEMOSA	12(11)	-(-)	-(-)	-(-)	57(5)	-(-)	4(6)	-(-)
POLEMONIUM PULCHERRIMUM	12(6)	-(-)	-(-)	7(2)	71(7)	6(T)	4(2)	-(-)
PYROLA SECUNDA	53(1)	60(3)	29(1)	71(3)	86(2)	19(1)	51(3)	27(3)
SENECIO TRIANGULARIS	12(33)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
SMILACINA STELLATA	35(6)	20(T)	43(2)	-(-)	-(-)	6(T)	10(1)	13(2)
STREPTOPUS AMPLEXIFOLIUS	18(9)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
THALICTRUM FENDLERI	71(3)	40(T)	43(3)	43(T)	43(3)	56(3)	49(3)	50(7)
TRIFOLIUM LONGIPES	24(7)	-(-)	-(-)	-(-)	-(-)	25(6)	4(4)	13(5)
EQUISETUM ARVENSE	6(4)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)

(con.)

APPENDIX C.—(Con.)

	ABLA/ RIMO MEAR	ABLA/ RIMO RIMO	ABLA/ CAGE	ABLA/ JUCO	ABLA/ CARO	ABCO/ CELE	ABCO/ ARPA	ABCO/ QUGA
NO. STANDS IN H.T.	37	128	6	25	27	9	12	7
TREES								
ABIES LASIOCARPA	100(45)	99(38)	100(57)	100(29)	100(47)	-(-)	-(-)	-(-)
ABIES CONCOLOR	3(2)	-(-)	-(-)	12(14)	-(-)	100(15)	100(11)	100(27)
PICEA ENGELMANNII	97(59)	94(52)	83(11)	76(35)	89(39)	-(-)	-(-)	-(-)
PICEA PUNGENS	-(-)	-(-)	-(-)	32(17)	11(1)	-(-)	17(5)	-(-)
PSEUDOTSUGA MENZIESII	3(1)	6(14)	17(3)	40(21)	26(32)	67(17)	100(13)	86(16)
PINUS FLEXILIS	5(1)	3(1)	-(-)	20(12)	11(4)	56(5)	75(13)	14(T)
PINUS LONGAEVA	-(-)	-(-)	-(-)	4(23)	-(-)	-(-)	25(7)	-(-)
PINUS PONDEROSA	-(-)	-(-)	-(-)	8(16)	4(22)	67(20)	100(16)	57(42)
POPULUS TREMULOIDES	27(27)	38(18)	100(70)	88(16)	85(20)	11(5)	8(5)	-(-)
PINUS EDULIS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	14(1)
JUNIPERUS SCOPULORUM	-(-)	-(-)	-(-)	-(-)	-(-)	44(3)	33(1)	71(1)
JUNIPERUS OSTEOSPERMA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
SHRUBS								
ACER GLABRUM	-(-)	-(-)	17(T)	-(-)	-(-)	11(T)	-(-)	-(-)
AMELANCHIER ALNIFOLIA	-(-)	-(-)	33(1)	16(T)	4(T)	67(2)	25(2)	57(13)
ARCTOSTAPHYLOS PATULA	-(-)	-(-)	-(-)	4(T)	4(50)	22(8)	100(9)	-(-)
ARCTOSTAPHYLOS UVA-URSI	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
ARTEMISIA NOVA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
ARTEMISIA TRIDENTATA	-(-)	2(2)	-(-)	4(2)	-(-)	22(T)	8(1)	-(-)
BERBERIS REPENS	-(-)	4(T)	67(T)	40(T)	26(T)	67(9)	83(2)	71(12)
CEANOTHUS MARTINII	-(-)	-(-)	-(-)	-(-)	-(-)	11(T)	8(T)	-(-)
CERCOCARPUS LEDIFOLIUS	-(-)	-(-)	-(-)	4(T)	-(-)	100(22)	8(2)	14(4)
CERCOCARPUS MONTANUS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	25(1)	14(8)
CHRYSOTHAMNUS PARRYI	-(-)	-(-)	-(-)	4(1)	-(-)	-(-)	17(T)	14(T)
CHRYSOTHAMNUS VISCIDIFLORUS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
JUNIPERUS COMMUNIS	11(2)	9(2)	33(1)	100(7)	33(T)	33(1)	58(2)	29(3)
LINNAEA BOREALIS	-(-)	-(-)	-(-)	4(5)	-(-)	-(-)	-(-)	-(-)
LONICERA INVOLUCRATA	14(2)	8(1)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
LONICERA UTAHENSIS	16(1)	5(3)	17(T)	12(1)	-(-)	-(-)	-(-)	-(-)
PACHISTIMA MYRSINITES	5(T)	8(T)	-(-)	12(T)	19(T)	33(1)	42(1)	29(2)
PHYSOCARPUS MALVACEUS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	14(T)
PRUNUS VIRGINIANA	-(-)	-(-)	-(-)	4(T)	-(-)	22(8)	-(-)	29(1)
PURSHIA TRIDENTATA	-(-)	-(-)	-(-)	4(T)	-(-)	22(1)	33(3)	29(4)
QUERCUS GAMBELII	-(-)	-(-)	17(3)	-(-)	-(-)	44(16)	17(13)	100(17)
RIBES CEREUM	5(1)	2(T)	-(-)	24(2)	-(-)	22(1)	50(T)	29(T)
RIBES MONTIGENUM	100(13)	100(7)	17(T)	16(T)	7(T)	-(-)	-(-)	-(-)
RIBES VISCOSISSIMUM	-(-)	2(1)	-(-)	-(-)	4(T)	-(-)	8(T)	-(-)
ROSA WOODSII	3(T)	5(1)	50(2)	52(1)	41(1)	33(1)	42(T)	43(2)
SALIX SCOULERIANA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
SAMBUCUS RACEMOSA	19(2)	27(2)	17(T)	4(T)	7(T)	-(-)	8(T)	43(T)
SHEPHERDIA CANADENSIS	-(-)	-(-)	-(-)	28(1)	4(T)	-(-)	8(T)	-(-)
SHEPHERDIA ROTUNDIFOLIA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
SYMPHORICARPOS OREOPHILUS	11(14)	30(1)	50(24)	40(2)	30(4)	67(6)	92(7)	71(11)
VACCINIUM CAESPITOSUM	-(-)	-(-)	-(-)	-(-)	4(T)	-(-)	-(-)	-(-)
VACCINIUM MYRTILLUS	5(3)	2(1)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
XANTHOCEPHALUM SAROTHRAE	-(-)	-(-)	-(-)	-(-)	-(-)	11(2)	17(T)	43(1)

(con.)

APPENDIX C.—(Con.)

NO. STANDS IN H.T.	ABLA/ RIMO MEAR 37	ABLA/ RIMO RIMO 128	ABLA/ CAGE 6	ABLA/ JUCO 25	ABLA/ CARO 27	ABCO/ CELE 9	ABCO/ ARPA 12	ABCO/ QUGA 7
GRAMINOIDS								
AGROPYRON SPICATUM	-(-)	2(2)	-(-)	-(-)	-(-)	11(4)	-(-)	-(-)
BOUTELOUA GRACILIS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
BROMUS CARINATUS	8(1)	2(1)	17(5)	-(-)	-(-)	11(1)	-(-)	-(-)
BROMUS CILIATUS	27(1)	40(2)	-(-)	28(2)	30(1)	11(T)	8(T)	14(T)
CAREX DISPERMA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
CAREX GEYERI	14(6)	6(9)	100(24)	-(-)	-(-)	11(1)	-(-)	43(1)
CAREX ROSSII	54(2)	51(2)	-(-)	88(1)	100(2)	78(4)	100(1)	71(1)
ELYMUS GLAUCUS	-(-)	4(1)	17(8)	-(-)	-(-)	-(-)	-(-)	-(-)
FESTUCA OVINA	11(1)	5(5)	-(-)	32(T)	19(1)	-(-)	-(-)	14(T)
GLYCERIA ELATA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
KOELERIA NITIDA	-(-)	1(1)	-(-)	8(1)	-(-)	11(T)	25(T)	-(-)
MUHLENBERGIA MONTANA	-(-)	-(-)	-(-)	4(2)	-(-)	11(2)	-(-)	14(1)
ORYZOPSIS HYMENOIDES	-(-)	-(-)	-(-)	-(-)	4(2)	11(T)	25(T)	-(-)
POA	16(2)	7(2)	-(-)	16(1)	11(1)	-(-)	8(1)	14(T)
POA FENDLERIANA	-(-)	2(1)	-(-)	36(1)	19(1)	67(4)	33(1)	71(1)
POA NERVOSA	3(T)	5(1)	-(-)	-(-)	7(T)	-(-)	-(-)	-(-)
POA PRATENSIS	-(-)	-(-)	33(23)	-(-)	-(-)	11(10)	-(-)	29(T)
SITANION HYSTRIX	3(T)	2(T)	-(-)	52(T)	19(T)	44(1)	58(1)	57(4)
STIPA COLUMBIANA	-(-)	-(-)	17(15)	-(-)	-(-)	33(2)	-(-)	14(1)
STIPA COMATA	-(-)	-(-)	-(-)	4(1)	-(-)	11(2)	8(1)	-(-)
STIPA LETTERMANII	3(T)	13(1)	17(2)	12(5)	7(T)	11(2)	8(T)	29(T)
TRISETUM SPICATUM	14(1)	14(1)	17(T)	12(T)	11(1)	-(-)	-(-)	-(-)
FORBS								
ACHILLEA MILLEFOLIUM	54(3)	42(1)	67(3)	32(1)	44(1)	22(T)	25(T)	43(T)
ACONITUM COLUMBIANUM	-(-)	1(T)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
ACTAEA RUBRA	3(T)	2(T)	17(T)	-(-)	-(-)	-(-)	-(-)	-(-)
AQUILEGIA COERULEA	62(2)	38(1)	33(1)	12(T)	26(1)	-(-)	-(-)	-(-)
ARABIS DRUMMONDII	5(2)	8(T)	-(-)	36(T)	19(1)	-(-)	17(T)	14(T)
ARNICA CORDIFOLIA	43(6)	41(4)	-(-)	8(T)	44(1)	-(-)	-(-)	-(-)
ASTER ENGELMANNII	5(1)	16(2)	-(-)	-(-)	7(2)	-(-)	-(-)	14(T)
ASTRAGALUS MISER	14(4)	16(1)	-(-)	32(1)	44(2)	-(-)	25(T)	-(-)
BALSAMORHIZA SAGITTATA	-(-)	-(-)	-(-)	-(-)	-(-)	11(4)	17(T)	43(5)
DELPHINIUM BARBEYI	27(5)	6(3)	17(2)	-(-)	-(-)	-(-)	-(-)	-(-)
DELPHINIUM OCCIDENTALE	14(3)	7(4)	-(-)	-(-)	4(4)	-(-)	-(-)	-(-)
EPILOBIUM ANGUSTIFOLIUM	30(1)	23(1)	17(T)	40(1)	26(1)	-(-)	-(-)	-(-)
ERIGERON PEREGRINUS	8(1)	12(1)	-(-)	16(T)	11(T)	-(-)	-(-)	-(-)
ERIOGONUM RACEMOSUM	-(-)	-(-)	-(-)	-(-)	-(-)	22(T)	17(T)	57(T)
GERANIUM RICHARDSONII	32(4)	11(1)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
GERANIUM VISCOSISSIMUM	-(-)	6(1)	33(2)	20(1)	4(T)	-(-)	17(T)	29(T)
HAPLOPAPPUS PARRYI	22(5)	10(1)	-(-)	12(T)	26(1)	-(-)	-(-)	-(-)
HELENIUM HOOPESII	8(3)	25(2)	50(1)	4(T)	4(4)	-(-)	-(-)	-(-)
HERACLEUM LANATUM	3(4)	4(1)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
HYMENOXYS RICHARDSONII	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	14(T)
LATHYRUS LANSZWERTII	16(9)	37(5)	67(15)	4(T)	22(2)	-(-)	8(T)	29(1)
LATHYRUS PAUCIFLORUS	3(40)	7(6)	-(-)	-(-)	-(-)	22(T)	-(-)	43(1)
LIGUSTICUM PORTERI	24(10)	13(1)	50(1)	4(T)	7(1)	-(-)	-(-)	14(1)
LUPINUS ARGENTEUS	24(5)	14(3)	-(-)	8(T)	26(2)	-(-)	-(-)	-(-)
MERTENSIA ARIZONICA	54(10)	19(1)	-(-)	4(2)	7(6)	-(-)	-(-)	-(-)
MERTENSIA CILIATA	5(6)	15(1)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
OSMORHIZA CHILENSIS	86(9)	76(3)	100(1)	-(-)	15(2)	11(1)	-(-)	14(T)
PEDICULARIS RACEMOSA	19(8)	5(3)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
POLEMONIUM PULCHERRIMUM	41(6)	8(1)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
PYROLA SECUNDA	43(3)	41(2)	17(2)	12(1)	26(1)	-(-)	-(-)	-(-)
SENECIO TRIANGULARIS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
SMILACINA STELLATA	3(T)	5(3)	67(5)	4(T)	-(-)	-(-)	-(-)	-(-)
STREPTOPUS AMPLEXIFOLIUS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
THALICTRUM FENDLERI	65(7)	54(3)	100(11)	16(T)	26(1)	33(T)	8(T)	-(-)
TRIFOLIUM LONGIPES	-(-)	12(1)	-(-)	4(2)	11(1)	-(-)	-(-)	-(-)
EQUISETUM ARVENSE	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)

(con.)

APPENDIX C.—(Con.)

	ABCO/ BERE JUCO	ABCO/ BERE BERE	ABCO/ JUCO	ABCO/ SYOR	PIEN/ RIMO	PIPU/ EQAR	PIPU/ JUCO	PIPU/ BERE
NO. STANDS IN H.T.	13	26	5	11	20	5	13	12
TREES								
ABIES LASIOCARPA	15(1)	8(1)	20(T)	-(-)	15(1)	20(13)	15(T)	25(1)
ABIES CONCOLOR	100(39)	100(37)	100(39)	100(23)	-(-)	-(-)	-(-)	-(-)
PICEA ENGELMANNII	15(5)	-(-)	-(-)	-(-)	100(54)	20(5)	-(-)	8(1)
PICEA PUNGENS	38(38)	19(12)	40(23)	9(T)	-(-)	100(53)	100(38)	100(21)
PSEUDOTSUGA MENZIESII	85(22)	92(31)	80(6)	82(32)	-(-)	40(1)	23(15)	42(24)
PINUS FLEXILIS	54(9)	27(5)	60(6)	9(1)	-(-)	-(-)	23(2)	50(7)
PINUS LONGAEVA	15(10)	4(19)	20(65)	-(-)	-(-)	-(-)	8(1)	8(6)
PINUS PONDEROSA	54(15)	38(17)	20(T)	73(16)	-(-)	-(-)	38(11)	25(38)
POPULUS TREMULOIDES	62(26)	42(16)	60(33)	18(2)	15(7)	80(15)	38(32)	58(12)
PINUS EDULIS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
JUNIPERUS SCOPULORUM	15(T)	38(2)	20(15)	45(4)	-(-)	-(-)	46(7)	25(1)
JUNIPERUS OSTEOSPERMA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
SHRUBS								
ACER GLABRUM	31(2)	8(1)	-(-)	-(-)	-(-)	-(-)	-(-)	8(T)
AMELANCHIER ALNIFOLIA	38(1)	62(1)	20(T)	45(3)	-(-)	-(-)	23(1)	8(T)
ARCTOSTAPHYLOS PATULA	8(T)	15(T)	20(T)	9(T)	-(-)	-(-)	8(2)	-(-)
ARCTOSTAPHYLOS UVA-URSI	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	31(6)	-(-)
ARTEMISIA NOVA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
ARTEMISIA TRIDENTATA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	25(1)
BERBERIS REPENS	100(11)	100(13)	40(T)	55(T)	-(-)	-(-)	46(2)	75(2)
CEANOTHUS MARTINII	8(1)	8(T)	-(-)	9(T)	-(-)	-(-)	8(T)	-(-)
CERCOCARPUS LEDIFOLIUS	-(-)	4(T)	-(-)	-(-)	-(-)	-(-)	8(T)	-(-)
CERCOCARPUS MONTANUS	-(-)	4(T)	-(-)	27(1)	-(-)	-(-)	-(-)	8(1)
CHRYSOTHAMNUS PARRYI	-(-)	4(T)	-(-)	18(5)	-(-)	-(-)	8(T)	8(T)
CHRYSOTHAMNUS VISCIDIFLORUS	-(-)	8(T)	-(-)	-(-)	-(-)	-(-)	15(T)	-(-)
JUNIPERUS COMMUNIS	100(12)	27(2)	100(20)	18(T)	20(1)	20(T)	100(18)	67(1)
LINNAEA BOREALIS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
LONICERA INVOLUCRATA	-(-)	-(-)	-(-)	-(-)	-(-)	20(30)	8(1)	-(-)
LONICERA UTAHENSIS	8(1)	-(-)	20(T)	-(-)	-(-)	-(-)	15(1)	-(-)
PACHISTIMA MYRSINITES	85(2)	58(3)	20(1)	27(T)	-(-)	20(T)	38(2)	50(1)
PHYSOCARPUS MALVACEUS	8(4)	8(1)	-(-)	9(1)	-(-)	-(-)	-(-)	-(-)
PRUNUS VIRGINIANA	-(-)	4(4)	-(-)	-(-)	-(-)	-(-)	-(-)	8(T)
PURSHIA TRIDENTATA	-(-)	8(T)	-(-)	36(T)	-(-)	-(-)	23(T)	17(2)
QUERCUS GAMBELII	8(3)	19(1)	-(-)	36(1)	-(-)	-(-)	-(-)	8(T)
RIBES CEREUM	15(T)	27(1)	40(8)	45(1)	-(-)	-(-)	15(T)	42(1)
RIBES MONTIGENUM	8(1)	-(-)	-(-)	-(-)	100(8)	-(-)	-(-)	8(1)
RIBES VISCOSISSIMUM	8(7)	8(1)	20(1)	-(-)	-(-)	-(-)	8(1)	-(-)
ROSA WOODSII	92(1)	62(1)	40(T)	55(2)	5(T)	60(5)	77(2)	67(1)
SALIX SCOULERIANA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
SAMBUCUS RACEMOSA	-(-)	12(1)	-(-)	18(T)	-(-)	20(1)	8(T)	-(-)
SHEPHERDIA CANADENSIS	8(1)	4(1)	20(T)	9(T)	-(-)	-(-)	31(8)	33(2)
SHEPHERDIA ROTUNDIFOLIA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
SYMPHORICARPOS OREOPHILUS	92(5)	100(11)	80(1)	100(16)	-(-)	60(1)	85(3)	75(10)
VACCINIUM CAESPITOSUM	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
VACCINIUM MYRTILLUS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
XANTHOCEPHALUM SAROTHRAE	-(-)	8(1)	-(-)	27(2)	-(-)	-(-)	15(T)	8(T)

(con.)

APPENDIX C.—(Con.)

	ABCO/ BERE JUCO	ABCO/ BERE BERE	ABCO/ JUCO	ABCO/ SYOR	PIEN/ RIMO	PIPU/ EQAR	PIPU/ JUCO	PIPU/ BERE
NO. STANDS IN H.T.	13	26	5	11	20	5	13	12
GRAMINOIDS								
AGROPYRON SPICATUM	-(-)	4(T)	-(-)	9(5)	-(-)	-(-)	8(T)	-(-)
BOUTELOUA GRACILIS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	8(T)
BROMUS CARINATUS	-(-)	-(-)	20(T)	-(-)	-(-)	-(-)	8(T)	-(-)
BROMUS CILIATUS	46(1)	27(1)	20(1)	18(1)	-(-)	20(T)	38(1)	42(3)
CAREX DISPERMA	-(-)	-(-)	-(-)	-(-)	-(-)	80(15)	-(-)	-(-)
CAREX GEYERI	-(-)	19(13)	-(-)	-(-)	-(-)	-(-)	-(-)	8(T)
CAREX ROSSII	69(2)	77(1)	100(2)	91(1)	80(1)	-(-)	77(2)	83(2)
ELYMUS GLAUCUS	-(-)	4(T)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
FESTUCA OVINA	-(-)	4(T)	-(-)	-(-)	75(4)	-(-)	-(-)	25(1)
GLYCERIA ELATA	-(-)	-(-)	-(-)	-(-)	-(-)	100(12)	-(-)	-(-)
KOELERIA NITIDA	-(-)	-(-)	-(-)	27(1)	5(T)	-(-)	15(T)	-(-)
MUHLENBERGIA MONTANA	-(-)	4(T)	-(-)	9(T)	-(-)	-(-)	8(6)	17(8)
ORYZOPSIS HYMENOIDES	8(T)	12(1)	-(-)	36(T)	-(-)	-(-)	23(1)	25(1)
POA	15(T)	-(-)	20(T)	-(-)	40(1)	40(1)	8(T)	-(-)
POA FENDLERIANA	31(T)	35(1)	-(-)	64(4)	5(T)	-(-)	31(2)	33(6)
POA NERVOSA	15(8)	12(1)	-(-)	-(-)	5(T)	-(-)	-(-)	17(T)
POA PRATENSIS	-(-)	4(1)	-(-)	-(-)	-(-)	20(3)	8(T)	-(-)
SITANION HYSTRIX	31(T)	27(1)	20(3)	45(1)	10(T)	-(-)	46(1)	33(1)
STIPA COLUMBIANA	8(1)	12(1)	20(35)	9(T)	-(-)	-(-)	-(-)	17(3)
STIPA COMATA	-(-)	-(-)	20(3)	9(T)	-(-)	-(-)	-(-)	17(1)
STIPA LETTERMANII	15(T)	31(1)	20(T)	36(1)	15(1)	-(-)	23(T)	25(1)
TRISETUM SPICATUM	-(-)	8(T)	-(-)	-(-)	45(1)	-(-)	-(-)	-(-)
FORBS								
ACHILLEA MILLEFOLIUM	23(6)	27(T)	40(1)	27(T)	95(1)	60(T)	54(1)	50(1)
ACONITUM COLUMBIANUM	-(-)	-(-)	-(-)	-(-)	-(-)	40(2)	-(-)	-(-)
ACTAEA RUBRA	-(-)	-(-)	-(-)	-(-)	-(-)	40(1)	-(-)	-(-)
AQUILEGIA COERULEA	8(2)	12(1)	-(-)	-(-)	45(1)	-(-)	-(-)	17(T)
ARABIS DRUMMONDII	8(T)	8(T)	-(-)	-(-)	35(T)	-(-)	15(1)	17(T)
ARNICA CORDIFOLIA	8(3)	12(12)	40(1)	9(4)	20(2)	-(-)	-(-)	-(-)
ASTER ENGELMANNII	-(-)	15(1)	-(-)	-(-)	-(-)	-(-)	-(-)	8(T)
ASTRAGALUS MISER	38(1)	19(1)	40(1)	-(-)	50(4)	-(-)	15(1)	33(3)
BALSAMORHIZA SAGITTATA	-(-)	4(T)	-(-)	36(9)	-(-)	-(-)	-(-)	-(-)
DELPHINIUM BARBEYI	-(-)	-(-)	-(-)	-(-)	10(2)	-(-)	-(-)	-(-)
DELPHINIUM OCCIDENTALE	-(-)	-(-)	-(-)	-(-)	5(T)	-(-)	-(-)	8(T)
EPILOBIUM ANGUSTIFOLIUM	-(-)	-(-)	-(-)	-(-)	40(1)	40(1)	15(T)	-(-)
ERIGERON PEREGRINUS	-(-)	-(-)	-(-)	-(-)	15(T)	-(-)	8(T)	-(-)
ERIOGONUM RACEMOSUM	-(-)	12(T)	-(-)	36(T)	-(-)	-(-)	8(T)	17(T)
GERANIUM RICHARDSONII	-(-)	-(-)	-(-)	-(-)	-(-)	100(3)	-(-)	-(-)
GERANIUM VISCOSISSIMUM	31(T)	42(2)	20(T)	9(T)	-(-)	-(-)	46(1)	25(2)
HAPLOPAPPUS PARRYI	23(6)	8(T)	20(T)	-(-)	5(4)	-(-)	8(1)	-(-)
HELENIUM HOOPESII	-(-)	-(-)	20(T)	-(-)	20(T)	-(-)	8(T)	8(T)
HERACLEUM LANATUM	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
HYMENOXYS RICHARDSONII	-(-)	4(T)	-(-)	9(T)	-(-)	-(-)	23(1)	8(T)
LATHYRUS LANSZWERTII	15(3)	38(1)	20(T)	18(3)	-(-)	-(-)	-(-)	25(3)
LATHYRUS PAUCIFLORUS	15(3)	12(7)	-(-)	-(-)	-(-)	-(-)	-(-)	8(8)
LIGUSTICUM PORTERI	-(-)	12(1)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
LUPINUS ARGENTEUS	-(-)	-(-)	-(-)	-(-)	15(1)	-(-)	8(3)	8(T)
MERTENSIA ARIZONICA	-(-)	4(T)	-(-)	-(-)	20(5)	20(1)	-(-)	8(T)
MERTENSIA CILIATA	-(-)	-(-)	20(T)	-(-)	30(T)	20(T)	-(-)	-(-)
OSMORHIZA CHILENSIS	8(1)	12(1)	-(-)	-(-)	-(-)	60(1)	-(-)	8(T)
PEDICULARIS RACEMOSA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
POLEMONIUM PULCHERRIMUM	-(-)	-(-)	-(-)	-(-)	85(3)	-(-)	-(-)	-(-)
PYROLA SECUNDA	8(T)	-(-)	20(T)	-(-)	5(1)	-(-)	-(-)	-(-)
SENECIO TRIANGULARIS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
SMILACINA STELLATA	8(T)	8(1)	-(-)	-(-)	-(-)	80(2)	38(T)	17(1)
STREPTOPUS AMPLEXIFOLIUS	-(-)	-(-)	-(-)	-(-)	-(-)	20(2)	-(-)	-(-)
THALICTRUM FENDLERI	15(1)	42(2)	40(1)	36(2)	10(1)	60(6)	46(1)	25(T)
TRIFOLIUM LONGIPES	-(-)	8(2)	-(-)	-(-)	10(2)	20(T)	-(-)	17(2)
EQUISETUM ARVENSE	-(-)	-(-)	-(-)	-(-)	-(-)	100(22)	15(T)	-(-)

(con.)

APPENDIX C.—(Con.)

	PIFL- PILO	PSME/ CELE	PSME/ ARPA	PSME/ CEMO	PSME/ QUGA	PSME/ BERE PIPO	PSME/ BERE BERE	PSME/ SYOR
NO. STANDS IN H.T.	18	11	5	5	5	8	21	19
TREES								
ABIES LASIOCARPA	6(2)	-(-)	-(-)	-(-)	-(-)	13(T)	-(-)	5(T)
ABIES CONCOLOR	11(T)	18(2)	-(-)	20(3)	20(T)	-(-)	-(-)	-(-)
PICEA ENGELMANNII	6(4)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
PICEA PUNGENS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	5(3)	11(1)
PSEUDOTSUGA MENZIESII	61(16)	100(15)	100(8)	100(15)	100(27)	100(28)	100(62)	100(24)
PINUS FLEXILIS	89(26)	-(-)	40(T)	-(-)	-(-)	25(T)	10(6)	5(T)
PINUS LONGAEVA	44(22)	9(13)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
PINUS PONDEROSA	6(1)	18(18)	100(19)	20(T)	80(38)	100(33)	5(1)	74(31)
POPULUS TREMULOIDES	22(12)	18(20)	-(-)	-(-)	20(1)	50(12)	33(6)	37(3)
PINUS EDULIS	6(2)	18(14)	-(-)	60(13)	-(-)	-(-)	-(-)	5(T)
JUNIPERUS SCOPULORUM	22(2)	55(11)	100(3)	60(3)	40(2)	75(6)	29(2)	42(2)
JUNIPERUS OSTEOSPERMA	-(-)	-(-)	-(-)	40(10)	-(-)	-(-)	-(-)	-(-)
SHRUBS								
ACER GLABRUM	-(-)	9(T)	-(-)	-(-)	20(T)	-(-)	19(2)	-(-)
AMELANCHIER ALNIFOLIA	22(1)	9(T)	-(-)	-(-)	80(2)	88(T)	38(1)	26(1)
ARCTOSTAPHYLOS PATULA	6(30)	9(T)	100(14)	-(-)	-(-)	-(-)	-(-)	-(-)
ARCTOSTAPHYLOS UVA-URSI	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
ARTEMISIA NOVA	-(-)	9(3)	-(-)	-(-)	-(-)	-(-)	-(-)	11(4)
ARTEMISIA TRIDENTATA	22(4)	45(8)	-(-)	-(-)	-(-)	13(T)	14(1)	11(1)
BERBERIS REPENS	44(3)	45(4)	100(1)	40(1)	80(3)	100(7)	100(9)	47(T)
CEANOTHUS MARTINII	-(-)	-(-)	80(5)	-(-)	-(-)	25(1)	-(-)	5(T)
CERCOCARPUS LEDIFOLIUS	11(23)	100(22)	20(1)	-(-)	-(-)	-(-)	5(T)	-(-)
CERCOCARPUS MONTANUS	17(4)	-(-)	40(4)	80(12)	20(T)	-(-)	5(T)	5(T)
CHRYSOTHAMNUS PARRYI	-(-)	-(-)	20(T)	-(-)	-(-)	13(T)	-(-)	21(1)
CHRYSOTHAMNUS VISCIDIFLORUS	17(8)	27(1)	20(T)	-(-)	-(-)	25(T)	14(T)	21(1)
JUNIPERUS COMMUNIS	67(7)	9(T)	20(T)	20(5)	40(3)	50(5)	33(2)	21(1)
LINNAEA BOREALIS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
LONICERA INVOLUCRATA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
LONICERA UTAHENSIS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
PACHISTIMA MYRSINITES	22(1)	9(T)	-(-)	20(1)	40(2)	-(-)	48(1)	5(T)
PHYSOCARPUS MALVACEUS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
PRUNUS VIRGINIANA	11(2)	-(-)	-(-)	-(-)	20(T)	13(T)	10(1)	11(1)
PURSHIA TRIDENTATA	6(T)	27(1)	20(8)	20(T)	20(T)	50(2)	-(-)	26(3)
QUERCUS GAMBELII	-(-)	18(10)	40(1)	-(-)	100(20)	13(2)	5(4)	16(1)
RIBES CEREUM	56(7)	27(1)	40(T)	20(1)	60(2)	13(T)	10(2)	42(1)
RIBES MONTIGENUM	11(2)	-(-)	-(-)	-(-)	-(-)	-(-)	19(1)	-(-)
RIBES VISCOSISSIMUM	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	10(1)	5(T)
ROSA WOODSII	39(2)	9(4)	20(1)	-(-)	60(2)	50(T)	48(2)	37(1)
SALIX SCOULERIANA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
SAMBUCUS RACEMOSA	11(T)	9(6)	40(T)	-(-)	-(-)	-(-)	10(T)	11(T)
SHEPHERDIA CANADENSIS	6(3)	-(-)	-(-)	-(-)	-(-)	-(-)	10(T)	5(T)
SHEPHERDIA ROTUNDIFOLIA	-(-)	-(-)	20(2)	40(3)	-(-)	-(-)	-(-)	-(-)
SYMPHORICARPOS OREOPHILUS	72(10)	73(7)	80(3)	60(3)	100(32)	100(4)	95(15)	100(2)
VACCINIUM CAESPITOSUM	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
VACCINIUM MYRTILLUS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
XANTHOCEPHALUM SAROTHRAE	6(3)	9(1)	20(2)	20(T)	-(-)	25(T)	-(-)	16(1)

(con.)

APPENDIX C.—(Con.)

	PIFL- PILO	PSME/ CELE	PSME/ ARPA	PSME/ CEMO	PSME/ QUGA	PSME/ BERE PIPO	PSME/ BERE BERE	PSME/ SYOR
NO. STANDS IN H.T.	18	11	5	5	5	8	21	19
GRAMINOIDS								
AGROPYRON SPICATUM	6(1)	9(1)	20(7)	-(-)	-(-)	-(-)	10(1)	16(3)
BOUTELOUA GRACILIS	-(-)	-(-)	20(T)	20(T)	-(-)	-(-)	-(-)	11(1)
BROMUS CARINATUS	17(1)	-(-)	-(-)	-(-)	-(-)	-(-)	10(T)	5(T)
BROMUS CILIATUS	6(T)	-(-)	20(T)	-(-)	20(T)	13(T)	19(T)	16(T)
CAREX DISPERMA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
CAREX GEYERI	-(-)	-(-)	20(T)	-(-)	20(20)	-(-)	5(45)	11(2)
CAREX ROSSII	56(1)	45(1)	80(1)	80(T)	100(1)	100(1)	67(1)	74(1)
ELYMUS GLAUCUS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
FESTUCA OVINA	22(1)	9(T)	-(-)	20(T)	-(-)	38(2)	-(-)	37(1)
GLYCERIA ELATA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
KOELERIA NITIDA	6(2)	9(1)	20(T)	-(-)	60(2)	38(T)	5(T)	32(1)
MUHLENBERGIA MONTANA	11(9)	-(-)	20(T)	-(-)	40(T)	-(-)	-(-)	26(1)
ORYZOPSIS HYMENOIDES	11(3)	18(1)	40(T)	40(1)	20(T)	38(T)	-(-)	11(1)
POA	-(-)	-(-)	-(-)	-(-)	20(2)	-(-)	5(1)	-(-)
POA FENDLERIANA	22(1)	45(8)	80(2)	-(-)	100(2)	50(3)	24(1)	68(4)
POA NERVOSA	-(-)	-(-)	-(-)	-(-)	20(3)	-(-)	5(3)	5(T)
POA PRATENSIS	11(1)	9(6)	-(-)	-(-)	-(-)	-(-)	5(T)	5(1)
SITANION HYSTRIX	22(1)	18(4)	60(1)	20(T)	60(2)	100(1)	24(T)	74(1)
STIPA COLUMBIANA	6(T)	9(2)	-(-)	-(-)	-(-)	13(T)	14(1)	-(-)
STIPA COMATA	6(1)	27(1)	20(T)	-(-)	-(-)	13(3)	-(-)	16(4)
STIPA LETTERMANII	22(2)	9(3)	-(-)	-(-)	40(13)	25(T)	43(1)	5(2)
TRISETUM SPICATUM	6(T)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
FORBS								
ACHILLEA MILLEFOLIUM	33(1)	9(2)	40(T)	-(-)	40(1)	38(1)	5(T)	11(1)
ACONITUM COLUMBIANUM	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
ACTAEA RUBRA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
AQUILEGIA COERULEA	17(T)	-(-)	-(-)	-(-)	-(-)	-(-)	5(T)	-(-)
ARABIS DRUMMONDII	11(T)	9(T)	-(-)	-(-)	20(T)	25(T)	10(T)	5(T)
ARNICA CORDIFOLIA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	5(T)	-(-)
ASTER ENGELMANNII	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
ASTRAGALUS MISER	33(7)	-(-)	20(T)	20(1)	-(-)	38(1)	-(-)	-(-)
BALSAMORHIZA SAGITTATA	6(2)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
DELPHINIUM BARBEYI	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
DELPHINIUM OCCIDENTALE	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
EPILOBIUM ANGUSTIFOLIUM	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
ERIGERON PEREGRINUS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
ERIOGONUM RACEMOSUM	-(-)	18(T)	60(T)	-(-)	20(T)	25(T)	5(T)	21(T)
GERANIUM RICHARDSONII	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
GERANIUM VISCOSISSIMUM	11(T)	-(-)	-(-)	-(-)	-(-)	50(T)	5(T)	21(1)
HAPLOPAPPUS PARRYI	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
HELENIUM HOOPESII	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	5(2)
HERACLEUM LANATUM	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
HYMENOXYS RICHARDSONII	39(2)	18(1)	80(T)	20(T)	20(T)	13(1)	-(-)	47(1)
LATHYRUS LANSZWERTII	33(1)	18(15)	-(-)	-(-)	40(2)	-(-)	29(2)	11(2)
LATHYRUS PAUCIFLORUS	11(3)	9(2)	-(-)	-(-)	20(T)	-(-)	14(7)	-(-)
LIGUSTICUM PORTERI	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	10(1)	11(T)
LUPINUS ARGENTEUS	6(T)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	11(2)
MERTENSIA ARIZONICA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	5(T)	-(-)
MERTENSIA CILIATA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
OSMORHIZA CHILENSIS	-(-)	9(T)	-(-)	-(-)	-(-)	-(-)	24(1)	-(-)
PEDICULARIS RACEMOSA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
POLEMONIUM PULCHERRIMUM	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
PYROLA SECUNDA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
SENECIO TRIANGULARIS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
SMILACINA STELLATA	17(1)	-(-)	-(-)	-(-)	20(1)	-(-)	14(1)	-(-)
STREPTOPUS AMPLEXIFOLIUS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
THALICTRUM FENDLERI	-(-)	-(-)	-(-)	-(-)	40(2)	63(1)	48(1)	21(T)
TRIFOLIUM LONGIPES	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
EQUISETUM ARVENSE	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)

(con.)

APPENDIX C.—(Con.)

	PIPO/ CELE	PIPO/ ARPA	PIPO/ ARNO	PIPO/ PUTR	PIPO/ QUGA SYOR	PIPO/ QUGA QUGA	PIPO/ SYOR	PIPO/ MUMO
NO. STANDS IN H.T.	6	15	8	21	15	14	6	8
TREES								
ABIES LASIOCARPA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	17(T)	-(-)
ABIES CONCOLOR	17(T)	-(-)	-(-)	-(-)	-(-)	-(-)	17(T)	-(-)
PICEA ENGELMANNII	-(-)	7(1)	-(-)	5(T)	-(-)	-(-)	-(-)	-(-)
PICEA PUNGENS	-(-)	7(T)	13(1)	-(-)	-(-)	-(-)	-(-)	-(-)
PSEUDOTSUGA MENZIESII	17(1)	7(1)	25(T)	14(1)	13(1)	7(T)	33(T)	13(T)
PINUS FLEXILIS	-(-)	20(1)	25(4)	14(T)	-(-)	-(-)	-(-)	13(1)
PINUS LONGAEVA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
PINUS PONDEROSA	100(30)	100(31)	100(26)	100(35)	100(47)	100(45)	100(51)	100(34)
POPULUS TREMULOIDES	-(-)	-(-)	-(-)	-(-)	13(20)	-(-)	33(8)	13(T)
PINUS EDULIS	33(6)	-(-)	-(-)	14(1)	-(-)	7(25)	-(-)	13(7)
JUNIPERUS SCOPULORUM	83(9)	80(3)	75(2)	57(4)	27(2)	29(1)	33(1)	38(3)
JUNIPERUS OSTEOSPERMA	17(2)	-(-)	-(-)	-(-)	-(-)	7(20)	-(-)	13(T)
SHRUBS								
ACER GLABRUM	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
AMELANCHIER ALNIFOLIA	33(3)	20(2)	-(-)	10(T)	73(3)	50(2)	50(2)	13(T)
ARCTOSTAPHYLOS PATULA	-(-)	100(8)	-(-)	-(-)	7(T)	-(-)	-(-)	13(T)
ARCTOSTAPHYLOS UVA-URSI	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
ARTEMISIA NOVA	-(-)	7(T)	100(14)	-(-)	-(-)	-(-)	-(-)	25(T)
ARTEMISIA TRIDENTATA	50(13)	7(T)	25(1)	24(12)	27(5)	57(6)	17(1)	25(18)
BERBERIS REPENS	33(1)	73(1)	-(-)	48(1)	80(5)	64(5)	67(5)	25(T)
CEANOTHUS MARTINII	-(-)	40(2)	-(-)	14(T)	-(-)	7(T)	-(-)	-(-)
CERCOCARPUS LEDIFOLIUS	100(12)	-(-)	-(-)	5(T)	-(-)	7(1)	-(-)	-(-)
CERCOCARPUS MONTANUS	-(-)	13(8)	-(-)	5(1)	13(T)	7(T)	-(-)	-(-)
CHRYSOTHAMNUS PARRYI	-(-)	33(T)	50(1)	19(1)	-(-)	7(T)	-(-)	25(T)
CHRYSOTHAMNUS VISCIDIFLORUS	50(1)	13(T)	63(1)	19(3)	13(1)	7(2)	-(-)	38(T)
JUNIPERUS COMMUNIS	-(-)	-(-)	25(T)	5(T)	7(1)	-(-)	-(-)	-(-)
LINNAEA BOREALIS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
LONICERA INVOLUCRATA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
LONICERA UTAHENSIS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
PACHISTIMA MYRSINITES	-(-)	-(-)	-(-)	-(-)	7(T)	-(-)	-(-)	-(-)
PHYSOCARPUS MALVACEUS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
PRUNUS VIRGINIANA	17(2)	-(-)	-(-)	-(-)	7(T)	-(-)	-(-)	-(-)
PURSHIA TRIDENTATA	17(1)	67(4)	50(2)	100(8)	27(T)	43(T)	50(T)	75(T)
QUERCUS GAMBELII	33(24)	33(8)	13(T)	48(8)	100(35)	100(29)	100(1)	50(1)
RIBES CEREUM	17(1)	13(T)	25(T)	14(1)	7(1)	-(-)	-(-)	50(1)
RIBES MONTIGENUM	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
RIBES VISCOSISSIMUM	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
ROSA WOODSII	17(8)	7(T)	-(-)	5(T)	60(8)	21(1)	50(T)	-(-)
SALIX SCOULERIANA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
SAMBUCUS RACEMOSA	-(-)	20(T)	-(-)	5(T)	-(-)	7(T)	-(-)	-(-)
SHEPHERDIA CANADENSIS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
SHEPHERDIA ROTUNDIFOLIA	-(-)	-(-)	-(-)	5(1)	-(-)	7(3)	-(-)	13(2)
SYMPHORICARPOS OREOPHILUS	67(1)	33(1)	38(1)	62(2)	100(29)	71(2)	100(17)	75(1)
VACCINIUM CAESPITOSUM	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
VACCINIUM MYRTILLUS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
XANTHOCEPHALUM SAROTHRAE	-(-)	40(T)	38(1)	29(1)	20(1)	21(T)	50(T)	50(1)

(con.)

APPENDIX C.—(Con.)

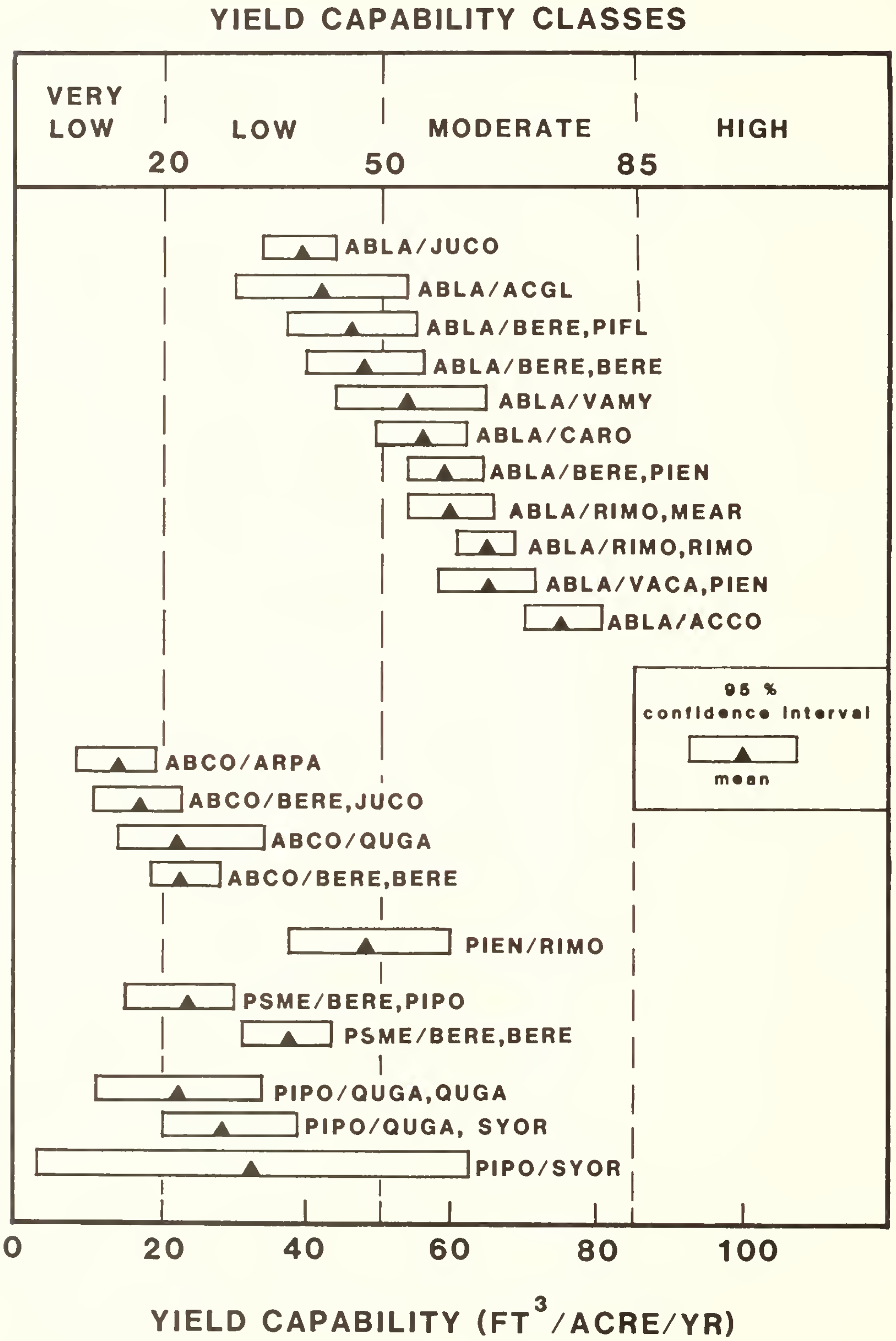
	PIPO/ CELE	PIPO/ ARPA	PIPO/ ARNO	PIPO/ PUTR	PIPO/ QUGA SYOR	PIPO/ QUGA QUGA	PIPO/ SYOR	PIPO/ MUMO
NO. STANDS IN H.T.	6	15	8	21	15	14	6	8
GRAMINOIDS								
AGROPYRON SPICATUM	-(-)	13(1)	13(T)	19(1)	-(-)	-(-)	-(-)	-(-)
BOUTELOUA GRACILIS	17(3)	7(T)	63(1)	38(1)	20(2)	21(1)	-(-)	50(2)
BROMUS CARINATUS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
BROMUS CILIATUS	-(-)	13(4)	13(T)	-(-)	27(1)	7(T)	17(T)	-(-)
CAREX DISPERMA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
CAREX GEYERI	-(-)	-(-)	-(-)	29(1)	33(24)	14(T)	-(-)	25(2)
CAREX ROSSII	33(1)	87(1)	38(3)	57(1)	73(1)	57(1)	83(1)	50(1)
ELYMUS GLAUCUS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
FESTUCA OVINA	-(-)	7(1)	13(1)	14(1)	-(-)	-(-)	-(-)	25(T)
GLYCERIA ELATA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
KOELERIA NITIDA	17(1)	20(1)	63(1)	33(2)	67(2)	57(3)	67(1)	-(-)
MUHLENBERGIA MONTANA	-(-)	13(T)	13(T)	43(1)	20(3)	21(1)	67(1)	50(1)
ORYZOPSIS HYMENOIDES	17(3)	53(1)	38(2)	38(T)	-(-)	7(T)	17(T)	63(1)
POA	-(-)	-(-)	-(-)	-(-)	7(T)	7(15)	17(2)	-(-)
POA FENDLERIANA	17(1)	47(2)	38(5)	81(6)	93(4)	86(4)	100(7)	88(2)
POA NERVOSA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
POA PRATENSIS	33(5)	7(T)	-(-)	-(-)	40(20)	7(15)	-(-)	-(-)
SITANION HYSTRIX	67(3)	47(1)	75(1)	90(4)	93(4)	79(2)	100(6)	100(3)
STIPA COLUMBIANA	-(-)	-(-)	-(-)	-(-)	27(3)	7(T)	-(-)	-(-)
STIPA COMATA	33(4)	20(1)	25(2)	38(1)	33(4)	36(4)	33(3)	38(T)
STIPA LETTERMANII	17(2)	13(2)	-(-)	5(2)	7(T)	-(-)	-(-)	-(-)
TRISETUM SPICATUM	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
FORBS								
ACHILLEA MILLEFOLIUM	17(T)	13(T)	13(T)	10(T)	73(1)	36(1)	50(2)	13(T)
ACONITUM COLUMBIANUM	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
ACTAEA RUBRA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
AQUILEGIA COERULEA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
ARABIS DRUMMONDII	-(-)	13(T)	-(-)	5(T)	20(T)	-(-)	-(-)	13(T)
ARNICA CORDIFOLIA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
ASTER ENGELMANNII	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
ASTRAGALUS MISER	-(-)	-(-)	-(-)	10(T)	-(-)	-(-)	-(-)	13(1)
BALSAMORHIZA SAGITTATA	-(-)	13(1)	-(-)	10(1)	13(T)	14(1)	-(-)	-(-)
DELPHINIUM BARBEYI	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
DELPHINIUM OCCIDENTALE	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
EPILOBIUM ANGUSTIFOLIUM	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
ERIGERON PEREGRINUS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
ERIOGONUM RACEMOSUM	67(T)	53(T)	75(T)	81(T)	60(T)	86(T)	83(T)	75(T)
GERANIUM RICHARDSONII	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
GERANIUM VISCOSISSIMUM	-(-)	-(-)	-(-)	-(-)	-(-)	7(T)	-(-)	13(T)
HAPLOPAPPUS PARRYI	-(-)	7(T)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
HELENIUM HOOPESII	-(-)	-(-)	-(-)	5(T)	-(-)	-(-)	-(-)	-(-)
HERACLEUM LANATUM	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
HYMENOXYS RICHARDSONII	33(T)	40(T)	75(1)	67(1)	-(-)	7(T)	50(T)	63(T)
LATHYRUS LANSZWERTII	17(T)	-(-)	-(-)	5(1)	40(3)	21(1)	33(2)	-(-)
LATHYRUS PAUCIFLORUS	-(-)	-(-)	-(-)	-(-)	13(3)	-(-)	-(-)	-(-)
LIGUSTICUM PORTERI	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
LUPINUS ARGENTEUS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	17(1)	-(-)
MERTENSIA ARIZONICA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
MERTENSIA CILIATA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
OSMORHIZA CHILENSIS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
PEDICULARIS RACEMOSA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
POLEMONIUM PULCHERRIMUM	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
PYROLA SECUNDA	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
SENECIO TRIANGULARIS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
SMILACINA STELLATA	-(-)	-(-)	13(T)	-(-)	7(1)	-(-)	-(-)	-(-)
STREPTOPUS AMPLEXIFOLIUS	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
THALICTRUM FENDLERI	-(-)	-(-)	-(-)	-(-)	7(1)	-(-)	-(-)	13(T)
TRIFOLIUM LONGIPES	-(-)	-(-)	-(-)	-(-)	7(2)	-(-)	-(-)	13(T)
EQUISETUM ARVENSE	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)

APPENDIX D.—MEAN BASAL AREAS AND 50-YEAR SITE INDEXES FOR CENTRAL AND SOUTHERN UTAH HABITAT TYPES AND PHASES

Means are shown where n = 4 or more; confidence limits (95 percent) for estimating the mean are given where n = 5 or more.

Habitat type, phase	Basal area (ft^2/acre)	Site index by species							Total number of site trees
		ABLA	ABCO	PIEN	PSME	PIPU	PIFL	PIPO	
ABLA/ACCO	233 ± 63	50 ± 10	•	56 ± 3	•	•	•	•	34
ABLA/VACA,PIEN	182 ± 56	52 ± 9	•	49 ± 4	•	•	•	•	31
ABLA /VAMY	306 ± ?	•	•	48 ± ?	•	•	•	•	7
ABLA/BERE,PIFL	224 ± 48	•	•	•	42 ± 9	•	•	•	16
ABLA/BERE,PIEN	208 ± 24	44 ± 5		49 ± 4	45 ± 7	42 ± ?	•	•	91
ABLA/BERE,BERE	181 ± 37	44 ± 11	•	•	35 ± 4	46 ± 7	•	•	26
ABLA/RIMO,MEAR	293 ± 43	42 ± 6	•	47 ± 6	•	•	•	•	34
ABLA/RIMO,RIMO	245 ± 17	45 ± 3	•	50 ± 2	45 ± 12	•	•	•	228
ABLA/JUCO	179 ± 24	33 ± 9	•	35 ± 6	30 ± 5	36 ± 7	•	•	40
ABLA/CARO	199 ± 22	44 ± 7	•	50 ± 4	35 ± 4	•	•	•	56
ABCO/CELE	101 ± 61	•	30 ± 8	•	32 ± 11	•	•	32 ± 11	12
ABCO/ARPA	122 ± 29	•	21 ± ?	•	34 ± 9	•	•	34 ± 9	11
ABCO/QUGA	128 ± 50	•	37 ± 7	•	47 ± 5	•	•	39 ± 12	11
ABCO/BERE,JUCO	189 ± 36	•	39 ± 14	•	40 ± 7	•	•	46 ± ?	18
ABCO/BERE,BERE	196 ± 24	•	38 ± 6	•	41 ± 4	•	•	36 ± 10	40
ABCO/SYOR	113 ± 25	•	31 ± ?	•	29 ± 8	•	•	30 ± 12	12
PIEN/RIMO	160 ± 64	•	•	38 ± 6	•	•	•	•	20
PIPU/JUCO	137 ± 32	•	•	•	•	41 ± 4	•	33 ± 12	19
PIPU/BERE	168 ± 71	•	•	•	33 ± 8	51 ± 7	•	42 ± 26	14
PIFL-PILO	130 ± 74	•	•	•	27 ± ?	•	19 ± ?	•	13
PSME/CELE	47 ± ?	•	•	•	27 ± 14	•	•	•	4
PSME/BERE,PIPO	150 ± 55	•	•	•	34 ± 5	•	•	42 ± 6	11
PSME/BERE,BERE	158 ± 36	•	•	•	36 ± 4	•	•	•	23
PSME/SYOR	126 ± 26	•	•	•	36 ± 6	•	•	40 ± 7	19
PIPO/CELE	57 ± 42	•	•	•	•	•	•	42 ± 14	6
PIPO/ARPA	81 ± 19	•	•	•	•	•	•	32 ± 3	25
PIPO/ARNO	73 ± 27	•	•	•	•	•	•	33 ± 8	10
PIPO/PUTR	87 ± 21	•	•	•	•	•	•	32 ± 3	29
PIPO/QUGA,SYOR	156 ± 27	•	•	•	•	•	•	40 ± 4	25
PIPO/QUGA,QUGA	134 ± 35	•	•	•	•	•	•	37 ± 4	27
PIPO/SYOR	150 ± 29	•	•	•	•	•	•	45 ± 9	7
PIPO/MUMO	100 ± 35	•	•	•	•	•	•	36 ± 5	12

APPENDIX E.—ESTIMATED YIELD CAPABILITIES FOR CENTRAL AND SOUTHERN UTAH HABITAT TYPES AND PHASES BASED UPON SITE INDEX, GROWTH, AND STOCKABILITY FACTORS



APPENDIX F.—SUBSTRATE FEATURES OF CENTRAL AND SOUTHERN UTAH HABITAT TYPES AND PHASES

Series	*Abies lasiocarpa*							
Habitat type	ACCO	VACA	VAMY	BERE	BERE	BERE	RIMO	RIMO
Phase		PIEN		PIFL	PIEN	BERE	MEAR	RIMO
No. of samples	**17**	**14**	**7**	**16**	**51**	**30**	**37**	**128**
	COARSE FRAGMENT TYPE (percent of samples)[1]							
SEDIMENTARY								
Limestone, dolomite[2]	12	•	•	56	38	13	24	35
Tertiary sandstone[3]	10	•	•	14	10	19	20	10
Cretaceous sandstone[4]	30	100	•	6	18	12	12	10
Jurassic sandstone[5]	•	•	•	•	2	•	•	2
Other sandstone[6]	•	•	•	•	•	•	•	1
METAMORPHIC								
Quartzite[7]	•	•	•	•	•	•	3	•
IGNEOUS								
Andesite[8]	36	•	100	12	16	28	24	16
Basaltic[9]	12	•	•	12	16	17	17	26
Unknown	•	•	•	•	•	11	•	•
	SUBSTRATE CHARACTERISTICS[10]							
EXPOSED ROCK (mean %)	3	2	4	5	8	6	5	4
BARE SOIL (mean %)	1	2	T	12	7	4	4	6
No. of observations	12	4	5	11	12	18	19	76
LITTER DEPTH (cm)	4.0	3.9	2.9	3.3	3.4	2.4	3.0	3.0
No. of observations	14	12	7	13	49	25	31	119

(con.)

APPENDIX F. (Con.)

Series	*Abies lasiocarpa*			*Abies concolor*					
Habitat type	**CAGE**	**JUCO**	**CARO**	**CELE**	**QUGA**	**ARPA**	**BERE**	**BERE**	**SYOR**
Phase							**JUCO**	**BERE**	
No. of observations	**6**	**25**	**27**	**9**	**7**	**12**	**13**	**26**	**11**
COARSE FRAGMENT TYPE (percent of samples)[1]									
SEDIMENTARY									
Limestone, dolomite[2]	·	8	15	12	14	73	53	30	45
Tertiary sandstone[3]	·	4	·	13	30	·	26	16	28
Cretaceous sandstone[4]	·	·	11	13	·	·	6	30	9
Jurassic sandstone[5]	·	·	·	·	14	·	·	·	·
Other sandstone[6]	·	·	·	·	·	18	·	·	·
METAMORPHIC									
Quartzite[7]	·	·	·	12	14	·	·	4	·
IGNEOUS									
Andesitic[8]	100	28	19	38	14	9	15	16	9
Basaltic[9]	·	56	48	12	14	·	·	4	9
Unknown	·	4	7	·	·	·	6	·	·
SUBSTRATE CHARACTERISTICS[10]									
EXPOSED ROCK (mean %)	T	15	5	5	7	3	3	8	3
BARE SOIL (mean %)	T	6	6	8	2	21	7	6	7
No. of observations	4	24	21	8	7	11	10	21	10
LITTER DEPTH (cm)	3.1	2.5	3.5	2.6	4.4	2.5	2.3	3.9	2.5
No. of observations	6	24	22	8	7	11	13	25	10

Series	*Picea engelmannii*	*Picea pungens*		*Pinus flexilis-Pinus longaeva*	*Pseudotsuga menziesii*		
Habitat type	**RIMO**	**JUCO**	**BERE**		**CELE**	**BERE**	**BERE**
Phase						**PIPO**	**BERE**
No. of observations	**20**	**13**	**12**	**18**	**11**	**8**	**21**
COARSE FRAGMENT TYPE (percent of samples)[1]							
SEDIMENTARY							
Limestone, dolomite[2]	5	53	18	28	·	26	5
Tertiary sandstone[3]	·	·	27	28	9	·	33
Cretaceous sandstone[4]	·	31	12	33	64	37	48
Jurassic sandstone[5]	·	·	·	·	·	·	·
Other sandstone[6]	·	·	·	·	·	·	·
METAMORPHIC							
Quartzite[7]	·	·	·	·	·	·	·
IGNEOUS							
Andesitic[8]	95	16	10	13	18	12	5
Basaltic[9]	·	·	27	16	9	25	10
Unknown	·	·	6	·	·	·	·
SUBSTRATE CHARACTERISTICS							
EXPOSED ROCK (mean %)	14	2	4	4	7	11	7
BARE SOIL (mean %)	11	9	13	32	8	6	5
No. of observations	20	11	9	14	4	8	10
LITTER DEPTH (cm)	2.5	3.0	2.4	1.8	1.3	2.4	3.2
No. of observations	14	13	10	14	10	7	18

(con.)

APPENDIX F. (Con.)

Series	*Pseudotsuga menziesii*	*Pinus ponderosa*							
Habitat type	**SYOR**	**CELE**	**ARPA**	**ARNO**	**PUTR**	**QUGA**	**QUGA**	**SYOR**	**MUMO**
Phase						**SYOR**	**QUGA**		
No. of observations	**19**	**6**	**15**	**8**	**21**	**15**	**14**	**6**	**8**
		COARSE FRAGMENT TYPE (percent of samples)[1]							
SEDIMENTARY									
Limestone, dolomite[2]	•	•	53	25	10	33	14	•	•
Tertiary sandstone[3]	11	33	•	•	4	•	•	•	12
Cretaceous sandstone[4]	•	•	7	13	•	27	21	•	•
Jurassic sandstone[5]	•	•	7	•	24	27	29	•	•
Other sandstone[6]	•	•	19	•	•	7	7	50	•
METAMORPHIC									
Quartzite[7]	•	•	•	•	•	•	•	•	•
IGNEOUS									
Andesitic[8]	•	67	7	•	9	•	7	•	25
Basaltic[9]	84	•	7	62	4	6	22	50	63
Unknown	5	•	•	•	•	•	•	•	•
		SUBSTRATE CHARACTERISTICS							
EXPOSED ROCK (mean %)	10	2	3	2	9	1	5	8	9
BARE SOIL (mean %)	11	4	13	4	4	3	4	2	3
No. of observations	18	6	15	8	21	15	14	6	8
LITTER DEPTH (cm)	3.4	3.9	2.8	3.2	3.2	5.5	4.3	4.6	4.9
No. of observations	17	5	15	8	21	15	14	6	6

---

[1] Based upon geology maps.

[2] Includes undifferentiated limestone and sandstones, and Flagstaff and Wasatch Formations of Tertiary Period, Cenozoic Era.

[3] Includes Duchesne River, Green River member of Parachute, Uinta, and North Horn Formations of Tertiary Period, Cenozoic Era.

[4] Includes Black Hawk Group, Kaiparowits, Straight Cliffs, Star Point, Price River, and Dakota member of Burrow Canyon Formations of Cretaceous Period, Mesozoic Era.

[5] Includes Morrison, Entrata, and Navajo Formations of Jurassic Period, Mesozoic Era.

[6] Includes Moss Back member of Chinle and Hoskinnini member of Moenkopi Formations of Triassic Period, Mesozoic Era; Weber and Morgan Formations of Paleozoic Era; and Mancos Formation of Cretaceous Period.

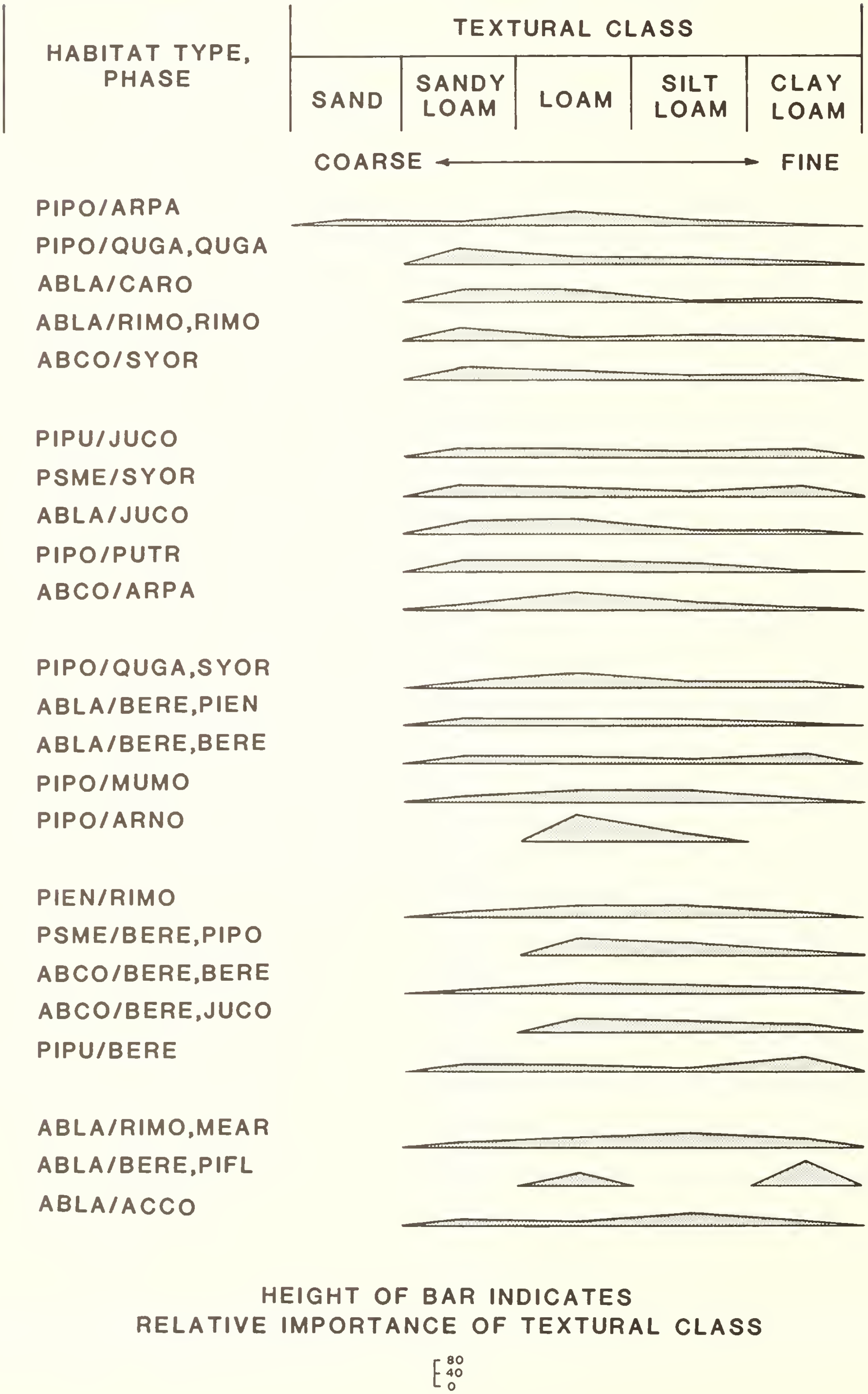
[7] Includes Tintic Formation and Prospect member of Pioche Formation of Cambrian Period, Paleozoic Era.

[8] Includes intrusive granitoids and porphyrites, andesitic pyroclastics, latite flows, latitic ignimbrites, and tuffs of Tertiary Period, Cenozoic Era.

[9] Includes basalt, basaltic, and andesitic flows, breccia, and basaltic pyroclastics of Quaternary and Tertiary Periods, Cenozoic Era.

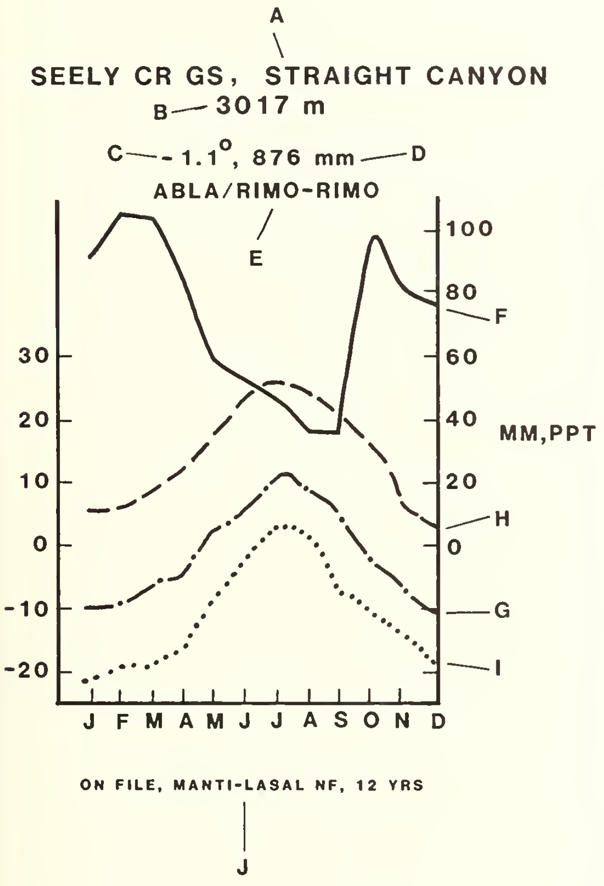
[10] T = trace.

APPENDIX G.—GENERALIZED SURFACE TEXTURAL RELATIONSHIPS FOR CENTRAL AND SOUTHERN UTAH HABITAT TYPES AND PHASES

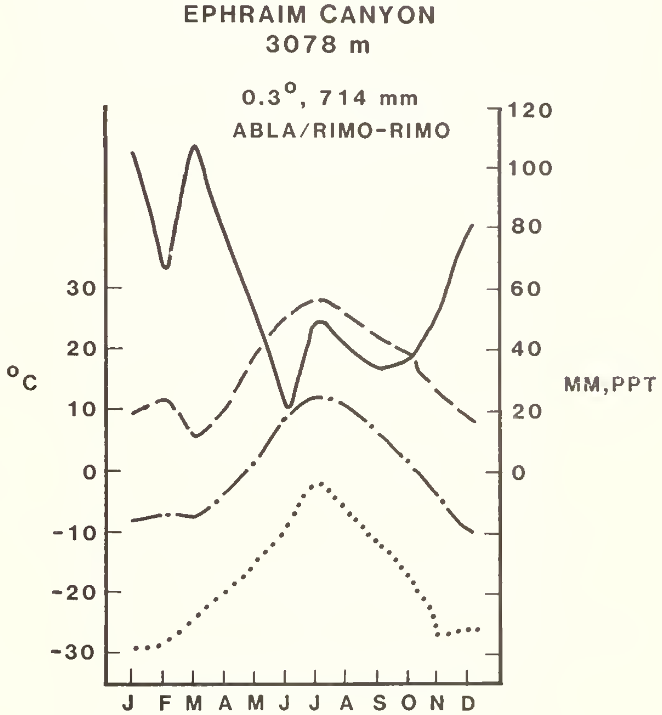


APPENDIX H.—CLIMATIC FACTORS FOR WEATHER STATIONS WITHIN SELECTED HABITAT TYPES IN CENTRAL AND SOUTHERN UTAH

A. Station location
B. Elevation (m)
C. Mean annual temperature (°C)
D. Mean annual precipitation (mm)
E. Habitat type for or adjacent to station
F. Pattern of mean monthly precipitation (mm)
G. Pattern of mean monthly temperature (°C)
H. Pattern of mean monthly maximim temperature (°C)
I. Pattern of mean monthly minimum temperature (°C)
J. Source of data and length of record



ON FILE, MANTI-LASAL NF, 12 YRS



PRICE & EVENS (1937), 20 YRS

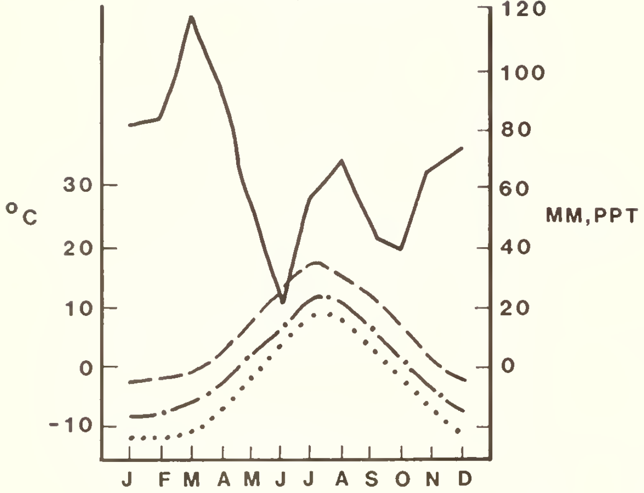
(con.)

APPENDIX H. (Con.)

BLOWHARD MTN RADAR
3260 m

1.2°, 796 mm

ABLA/RIMO, PIEN/RIMO

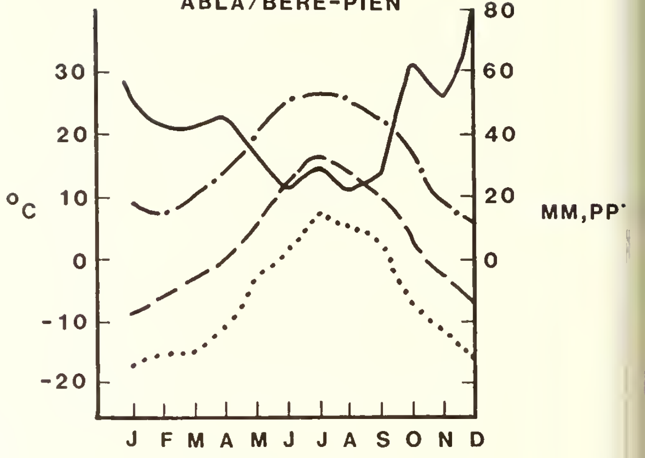


NOAA, PROJECTED BY RICHARDSON, 20 YRS

ELECTRIC LAKE
2545 m

2.7°, 518 mm

ABLA/BERE-PIEN

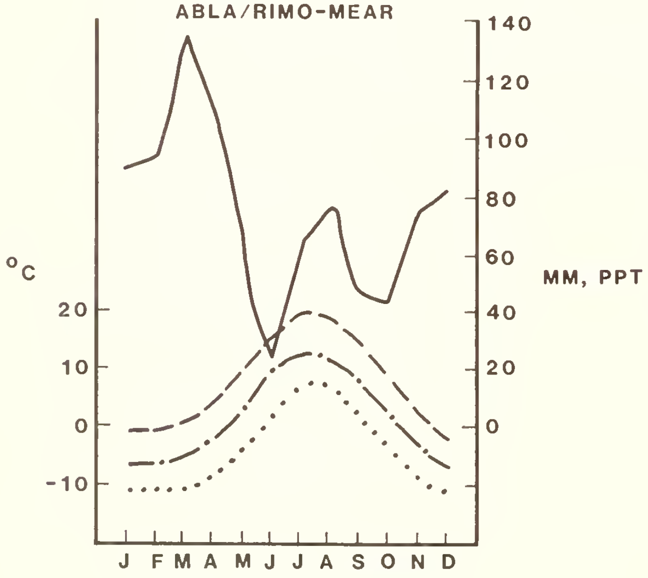


ON FILE, MANTI-LASAL NF, 7 YRS

BLOWHARD MTN SITE B
3084 m

1.9°, 897 mm

ABLA/RIMO-MEAR

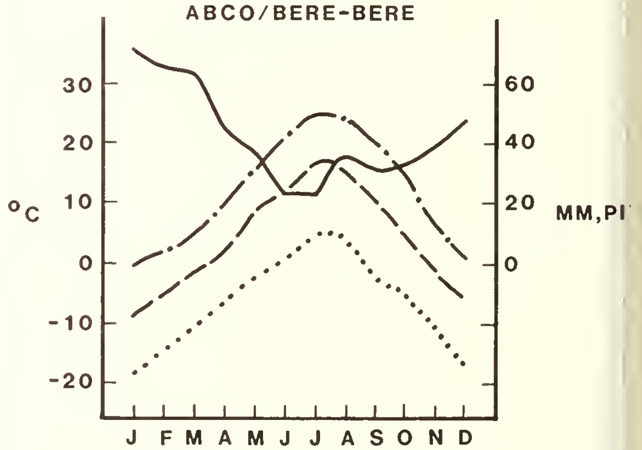


PROJECTED BY RICHARDSON

SCOFIELD
2353 m

3.9°, 515 mm

ABCO/BERE-BERE



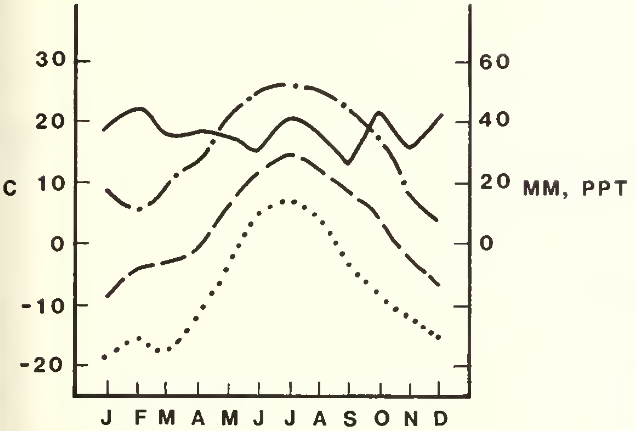
NOAA, 30 YRS

(cor

APPENDIX H. (Con.)

CENTRAL WEATHER,
STRAIGHT CANYON
2712 m

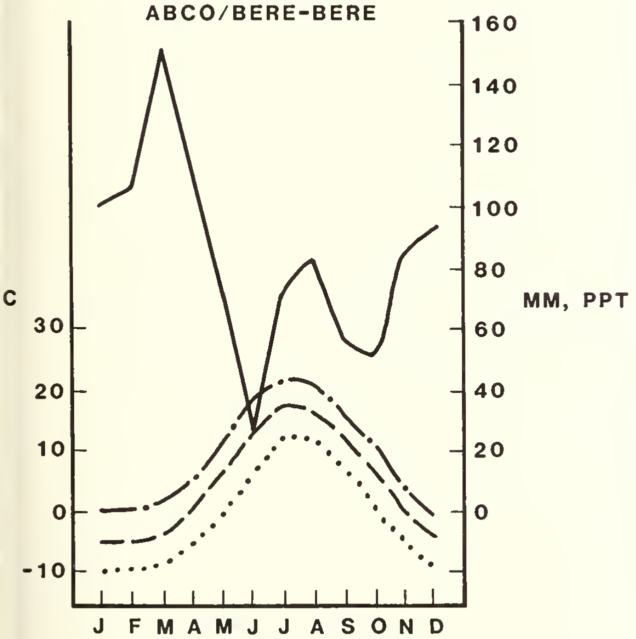
4.1°, 440 mm
ABCO/BERE-BERE



ON FILE, MANTI-LASAL NF, 12 YRS

BLOWHARD MTN SITE A
2682 m

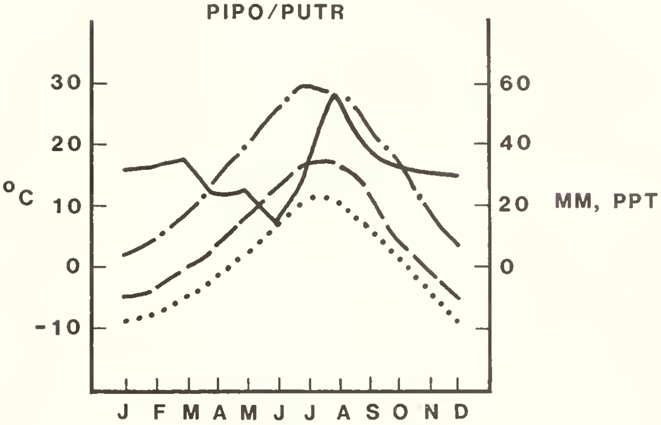
4.3°, 1019 mm
ABCO/BERE-BERE



PROJECTED BY RICHARDSON

BRYCE CANYON NP HDQ.
2412 m

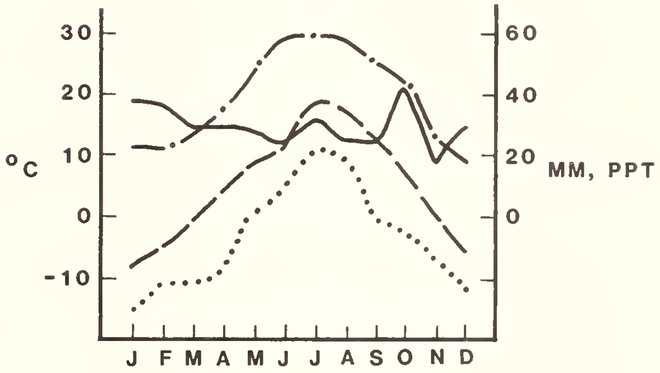
4.6°, 381 mm
PIPO/PUTR



NOAA, 30 YRS

ORANGE OLSEN GS,
STRAIGHT CANYON
2207 m

4.9°, 355 mm
PIPO/MUMO



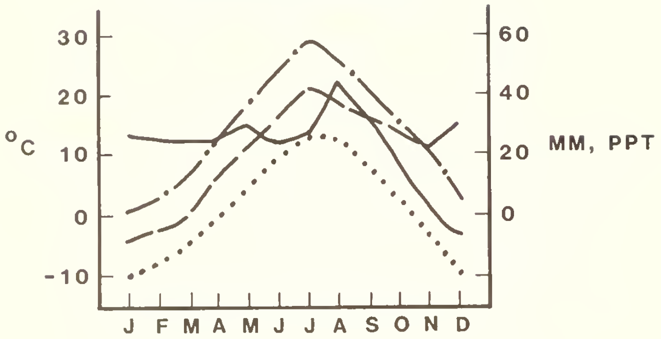
ON FILE, MANTI-LASAL NF, 12 YRS

(con.)

APPENDIX H. (Con.)

HIAWATHA
1859 m

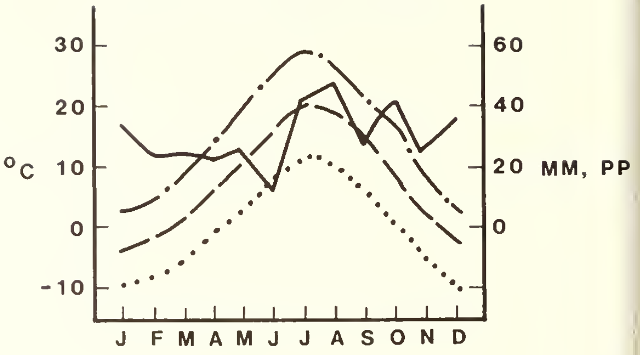
7.5°, 343 mm
below PSME/BERE-BERE



NOAA, 30 YRS

MONTICELLO
2079 m

8.0°, 366 mm
below PIPO/QUGA-QUGA



NOAA, 30 YRS

APPENDIX I.—CENTRAL AND SOUTHERN UTAH CONIFEROUS FOREST HABITAT TYPE FIELD FORM

NAME Date

Topography:	Horizontal Configuration	Plot Number
		Location
1- Ridge	1- Convex	T.R.S.
2- Upper slope	2- Straight	Elevation
3- Mid-slope	3- Concave	Aspect
4- Lower slope	4- Undulating	Slope
5- Bench or flat		Topography
6- Stream bottom		Configuration

SCIENTIFIC NAME	ABBREV	COMMON NAME	CANOPY COV (%)
TREES			
Abies concolor	ABCO	white fir	
Abies lasiocarpa	ABLA	subalpine fir	
Picea engelmannii	PIEN	Engelmann spruce	
Picea pungens	PIPU	blue spruce	
Pinus flexilis	PIFL	limber pine	
Pinus longaeva	PILO	bristlecone pine	
Pinus ponderosa	PIPO	ponderosa pine	
Pseudotsuga menziesii	PSME	Douglas-fir	
SHRUBS			
Acer glabrum	ACGL	mountain maple	
Arctostaphylos patula	ARPA	greenleaf manzanita	
Arctostaphylos uva-ursi	ARUV	bearberry	
Artemisia arbuscula	ARAR	low sagebrush	
Artemisia nova	ARNO	black sagebrush	
Berberis repens	BERE	Oregon grape	
Ceanothus martinii	CEMA	Martin ceanothus	
Cercocarpus ledifolius	CELE	curlleaf mountain-mahogany	
Cercocarpus montanus	CEMO	mountain-mahogany	
Juniperus communis	JUCO	common juniper	
Pachistima myrsinites	PAMY	myrtle pachistima	
Physocarpus malvaceus	PHMA	ninebark	
Purshia tridentata	PUTR	bitterbrush	
Quercus gambelii	QUGA	Gambel oak	
Ribes montigenum	RIMO	mountain gooseberry	
Shepherdia rotundiflora	SHRO	roundleaf buffaloberry	
Symphoricarpos oreophilus	SYOR	mountain snowberry	
Vaccinium caespitosum	VACA	dwarf huckleberry	
Vaccinium globulare	VAGL	blue huckleberry	
Vaccinium myrtillus	VAMY	myrtle whortleberry	
GRAMINOIDS			
Bouteloua gracilis	BOGR	blue grama	
Carex disperma	CADI	soft-leaved sedge	
Carex geyeri	CAGE	elk sedge	
Carex rossii	CARO	Ross sedge	
Glyceria elata	GLEL	tall mannagrass	
Muhlenbergia montana	MUMO	mountain muhly	
Oryzopsis hymenoides	ORHY	Indian ricegrass	
FORBS			
Aconitum columbianum	ACCO	monkshood	
Actaea rubra	ACRU	baneberry	
Equisetum arvense	EQAR	common horsetail	
Geranium richardsonii	GERI	Richardson geranium	
Mertensia arizonica	MEAR	Arizonica bluebells	
Mertensia ciliata	MECI	mountain bluebells	
Polemonium pulcherrium	POPU	skunkleaf polemonium	
Senecio triangularis	SETR	arrowleaf groundsel	
Trifolium longipes	TRLO	longstalk clover	

Series ____________________

Habitat Type ______________

Phase ____________________

Youngblood, Andrew P.; Mauk, Ronald L. Coniferous forest habitat types of central and southern Utah. General Technical Report INT-187. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station; 1985. 89 p.

A land-classification system based upon potential natural vegetation is presented for the coniferous forests of central and southern Utah. It is based on reconnaissance sampling of about 720 stands. A hierarchical taxonomic classification of forest sites was developed using the habitat type concept. Seven climax series, 37 habitat types, and six additional phases of habitat types are defined and described. A diagnostic key, using conspicuous indicator species, provides for field identification of the types.

KEYWORDS: forest vegetation, Utah, habitat types, plant communities, forest ecology, forest management, classification

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Mountain Pine Beetle Dynamics in Lodgepole Pine Forests

Part III: Sampling and Modeling of Mountain Pine Beetle Populations

**Walter E. Cole
Gene D. Amman
Chester E. Jensen**

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ACKNOWLEDGMENTS

With this final part of the three-part monograph on the mountain pine beetle, we would be remiss if we did not acknowledge the sustained effort and contributions of Lynn A. Rasmussen, biological technician for our research work unit. Lynn began work with the unit in 1965 and has been an integral, indispensable part of all aspects of our mission. His contributions not only include well-organized field scheduling and supervision of temporary crews, but also original ideas for research. In addition, he has demonstrated research ability on his own in the field and laboratory.

RESEARCH SUMMARY

Much of this work is original research by the authors. However, published literature on sampling and modeling of mountain pine beetle populations is reviewed primarily for epidemic beetle populations in lodgepole pine forests. Sampling methods are available for within-tree populations of beetles, for ground surveys of tree losses in stands, and for aerial survey to estimate tree losses over large areas. Models are presented for beetle survival, beetle dispersion, beetle aggregation, lodgepole pine stand-beetle interactions, and rate of tree loss to improve existing risk-rating models.

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COVER PHOTO: Lodgepole pine trees killed by mountain pine beetles on the Targhee National Forest in southeastern Idaho. INSERT: Lodgepole pine felled and sampled for mountain pine beetles.

P EFACE

he mountain pine beetle, *Dendroctonus ponderosae* H kins, is a native bark beetle whose depredations ca se various effects upon the lodgepole pine, *Pinus co torta* Dougl. ex Loud. var. *latifolia* Engelm., ecosyste . Historically, the beetle kills millions of trees each ye r in the United States and Canada. During epide nics, a single National Forest may lose in excess of a illion trees in a single year; for example, 3.6 million lo gepole pines were killed on the Targhee National F est, ID, in 1976 (Klein and others 1978). The mounta n pine beetle has killed an estimated average of 2 bi ion bd ft per year since 1895 (Wood 1963). In 1970, vo ume loss of growing stock to all mortality causes to aled some 613 million ft^3 (17.4 million m^3) within the R cky Mountain States; this is equivalent to nearly 75 pe cent of the volume of roundwood produced. In the sa e year, sawtimber volume losses were 208 million ft (5.9 million m^3), equivalent to nearly 50 percent of th volume of roundwood products from sawtimber (G een and Setzer 1974). The mountain pine beetle in lo gepole and ponderosa pines accounted for about 4 .3 million ft^3 (13.4 million m^3) or 77 percent of this vo ume loss. Similar losses could be expected in the W st Coast States. In western Canada, losses of lo gepole pine to the mountain pine beetle were estim ted to be 1.3 million ft^3 (36 900 m^3) per year betw en 1950 and 1970 (Safranyik and others 1974). This i pact places the mountain pine beetle as the prime in ect agent affecting the lodgepole pine ecosystem. T e effects of beetle infestations change the entire lo gepole pine environment and, depending on subseq ent occurrence or exclusion of fire, largely determ ne the nature of successional dynamics—enhancing lo gepole pine renewal in the case of fire, or success n of more shade-tolerant species in the absence of fi .

ree mortality in pine stands can occur as scattered in ividual trees, but more often trees are killed in g ups. Unchecked, these groups expand with succe ding beetle generations, and eventually large areas m y suffer extreme losses of their forest cover. This m y or may not be catastrophic, depending on lando ner objectives. Some landowners, for example, favor g ssland over timberland and a bark beetle outbreak m y be beneficial to them. On the other hand, the value of a mountain home may be severely reduced by the death of high-value shade trees, and the owner may view this loss as highly undesirable. From the timber-producer standpoint, the beetle can disrupt management plans and cause an unwelcomed impact on local, regional, and national economies.

This treatise represents much original research by the authors, but it also is a review of other published literature about the mountain pine beetle, with particular reference to epidemic infestations. Much research remains to be done in testing and applying management strategies indicated by this research. In addition, the dynamics of mountain pine beetle populations during endemic periods are in need of study. During periods of low beetle activity, we believe significant "keys" exist that will permit more effective management of stands to prevent increases in beetle populations.

Our research approach first addressed the recognition and determination of relationships between the insect and its associated environmental factors. These relationships, based on biological functions, were studied to determine their biological effect upon the insect. Second, quantification of these relationships was based upon measurement units relative to beetle behavior. The host variable was considered as an integral unit within the ecosystem.

Our intent is to lead readers through this maze of interactive relationships to the extent of their interest and existing knowledge. With this in mind, we have prepared three publications, the last of which is this current one:

Part I. Course of Infestation—including beetle impact on the lodgepole pine stand, how the beetle "moves through" the stand, expected timber mortality, and management alternatives.

Part II. Mountain Pine Beetle Population Dynamics—including bionomics, analyses of mortality factors, entomological relationships, and the "inner workings" of a mountain pine beetle population.

Part III. Sampling and Modeling of Mountain Pine Beetle Populations—including methods of sampling and modeling both lodgepole pine and mountain pine beetle populations.

Mountain Pine Beetle Dynamics in Lodgepole Pine Forests
Part III: Sampling and Modeling of Mountain Pine Beetle Populations

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SAMPLING

Sampling—the foundation of any mensurational aspect
population ecology—is basic to subsequent steps in
aluating actions and interactions of individual factors,
oups of factors affecting population behavior, and sub-
quent model building. Sampling schemes and sample
its should be based on the behavior of the insect and
ed as mensurational and analytical tools to provide ac-
rate and realistic insight into populations of insects.
ch "behavioral sampling units" must have biological
ativity to the insect-environment association and, in
rticular, to the life processes of the insect (Cole 1967).

The use of area samples alone may have little biologi-
l meaning in reference to a particular insect. The num-
r of bark beetles per unit area merely indicates the
nsity of the insect population, which, although desira-
e in many cases, may only reflect convenience to the
mpler. Expressing a population with respect to an area
hat is, as absolute density) neither describes the differ-
g biological implications of individuals living in an as-
ciation nor the insect-host biological relationship.
herefore, the principal objective of any sampling proce-
re is to secure a sample that, subject to physical limi-
tion, will reproduce the characteristics of that popula-
on as closely as possible.

Our approach to studying the dynamics of mountain
ne beetle populations involved two main sampling
ocedures: (1) the sampling of stands to determine the
haracteristics of trees and stands infested by mountain
ne beetles, and (2) the sampling of beetle populations
ithin trees to determine factors affecting natality and
ortality and for predicting population trends.

A distinction is made here between sampling for popu-
tion dynamics research purposes and sampling for
end prediction in surveys. The requirements for the
wo are substantially different. The first attempts to de-
ne the real causes of population fluctuations; the latter
more directly involved in applied forest entomology.
owever, once the causes of population fluctuations are
etermined, then reliable sampling schemes for trend
redictions can be readily developed.

Sampling Stands

Sampling stands can be done by ground surveys where
mited area is involved and detailed measurements of
ees are needed, or by aerial surveys where large areas
re involved and less detailed tree information is
equired.

Ground surveys.—Most sampling of mountain pine beetle-infested trees has been directed toward estimating the incidence of attacked trees. The primary use of results was for planning control operations. Survey methods were usually the "line-strip" or "strip-plot" methods. Knight (1958) compared three plot sizes and two strip widths for estimating mountain pine beetle-infested trees in ponderosa pine stands. These were:

—0.1-acre (0.04-ha) plots at 2-chain (40-m) intervals along parallel cruise lines.

—0.2-acre (0.08-ha) plots at 2.5-chain (50-m) intervals along parallel cruise lines.

—0.25-acre (0.10-ha) plots at 2.5-chain (50-m) intervals along parallel cruise lines.

—Parallel cruise lines of 0.5-chain (10-m) width.

—Parallel cruise lines of 1-chain (20-m) width.

Knight (1958) concluded that the five methods gave approximately equal results when the same number of cruise lines were used. He stated that although no method was superior, results favor the 0.5-chain strip method. It and the 0.1-acre plot method will be conducted faster than the other methods, but the 0.5-chain strip method was selected because inexperienced personnel could be trained more quickly to obtain accurate results. Sampling errors for all methods were influenced by acreage, survey coverage, and number of trees infested.

Parker (1972) tested the 0.1-acre fixed plot, 0.5-acre (0.20-ha) strip plot, and two variable plot sizes of 5 basal area factor (BAF) and 10 BAF to determine which gave the best estimate of lodgepole pine losses to mountain pine beetles. These were compared to a tally of all infested trees within the study area. Parker found no appreciable differences among these methods in estimating numbers of trees killed per acre by mountain pine beetles. Losses estimated from the 0.5-acre strip plot method correlated closer with the tally of all infested trees, but more time was required for plot measurements.

Initially, we (Cole and Amman 1969) settled on line-plot sampling using 0.1-acre fixed radius plots. Plots were located equidistant on parallel lines throughout the area of interest. The 0.1-acre plots were thus in a grid pattern. The fixed radius plots were selected because more small diameter, infested trees would be measured than with variable plot cruising. We were especially interested in the small diameter trees because mountain pine beetle epidemics rarely, if ever, start in stands consisting of small diameter trees. We were interested in knowing:

1. Types of trees the mountain pine beetle kills.
2. Beetle production in different types of trees.
3. Tree characteristics associated with high brood production.

Initially, 20 plots of 0.1 acre (0.04 ha) fixed-diameter were systematically located in a grid pattern within a 2-mile (3.2-km) square unit (Cole and Amman 1969). We initially chose the large area because we wanted to sample beetle losses over the full range of stand conditions one might encounter in lodgepole pine stands. From this information we could explore tree losses in relation to elevation, stand density, and stand structure. Beetle production could be measured on each infested tree and related to the above factors, as well as to individual tree characteristics.

All trees within the sample plot were recorded by (1) diameter at breast height, (2) total height, (3) crown class, (4) living or dead, (5) year of death, and (6) cause of death. Year of death, if there was a need to postdate death, was estimated by foliage, twig, and other characteristics: (1) foliage green, fresh boring frass, larvae or eggs present—killed in current year; (2) foliage bright orange to straw color—killed in previous year; (3) foliage dull orange and most retained—killed in second year past; (4) foliage dull orange to gray and most lost—killed in third year past; (5) no foliage, most small twigs supporting needle fascicles lost—killed in fourth year past; (6) many larger twigs lost, bark peeling—killed in fifth year past or before. Parker (1973) said he could not accurately determine year of death for trees that died more than 1 year previously. However, the close resemblance of curves showing loss by year of death by Cole and Amman (1969) and information in Gibson (1943) suggest that the criteria used by Cole and Amman for dating year of tree death are reasonably accurate.

Estimates of the average diameter of trees killed by the beetle per year gave coefficients of variation that were usually less than 10 percent.

As scientists have gained knowledge about the mountain pine beetle, estimates have been improved by stratifying according to various factors that influenced tree losses—for example, elevation (Amman and Baker 1972) and habitat type (Roe and Amman 1970; McGregor 1978; Cole and McGregor 1983). The procedure for estimating lodgepole pine losses to mountain pine beetles in Forest Service Northern Region is to use ten 10-BAF plots located in a grid pattern within a habitat type (McGregor, personal communication, April 1982). However, once again, a reminder that the aims of survey and research purposes are different and, consequently, may dictate different sampling schemes.

Aerial surveys.—Ground surveys for estimating tree mortality and trends in mountain pine beetle infestations proved quite acceptable for small areas or single stands. However, the areas sampled usually represent a small portion of the total acreage infested during a beetle outbreak. For large areas, large-scale color aerial photography using 70 mm or larger format has proved quite efficient for detecting beetle-infested or killed timber (Wea and others 1966).

Color and black and white films were tested at two scales (1:7,920 and 1:15,840) to detect ponderosa pine killed by mountain pine beetle in the Black Hills (Helle and others 1959). There was no significant difference among estimates by observer, but a highly significant difference between films. Panchromatic film gave poor results, whereas Ektachrome yielded excellent results. Using color film, experienced interpreters obtained estimates within a 5 percent error.

Estimating dead trees more than 1 year old from tru color aerial photos at scales of 1:1,600 and 1:2,400 presents some serious problems. For example, a high percentage of trees are missed and others are incorrect identified (Hamilton 1981).

A color stereophotographic procedure using a 35-mm camera from light aircraft to quantify mountain pine beetle-killed lodgepole pine was developed (Klein 1973). Mortality estimates from photos were highly correlate with ground counts ($r^2 = 0.90$), and the highest correlation was new faders ($r^2 = 0.94$). Photo counts usually were less than ground counts, but these errors of omission were attributed to small dead trees in the understory that were not visible to the camera. The effectiveness of aerial measurement technique, applied in the framework of double sampling designs, can aid tremendously in estimating total tree loss within large manag ment units. This method was further refined with high altitude, panoramic photography using KA-80A optical bar photography as an alternative to frame photography. The panoramic color IR aerial photography provided the data base for a multistage survey using probability proportional to size (PPS) at three levels to estimate numbers of trees and volume killed. Standard errors using this method were 10.3 percent for number of trees killed and 13.6 percent for volume estimates. These errors were judged quite acceptable (Klein 1982). The greatest handicap of aerial methods is that trees i fested the year before are counted; thus, data obtained are almost 1 year old. Consequently, time is limited to make and implement management decisions before beetles emerge to infest green trees.

Sampling Beetle Populations

Sampling mountain pine beetle populations is accomplished primarily using the destructive sampling meth of bark removal without replacement, but may also be done by indirect methods such as radiography. Samplin yields insights into causes of beetle mortality and tren in population change.

Bark removal method.—Sampling mountain pine beet populations involves counting the beetles during variou stages of the beetle's life cycle in sampling units within infested trees. Carlson and Cole (1965) developed a system for sampling mountain pine beetle in lodgepole pin trees. The experimental work was done within two stands, one on the Wasatch-Cache National Forest in northern Utah and the other on the Bridger-Teton National Forest in Wyoming. The insect populations were considered epidemic at that time.

The experiment was designed to test for variation be- veen sample sizes, shapes, location within the tree, and ameter at breast height (d.b.h.) of the tree. Three vari- bles were measured: (1) density of attacking parent bee- es, (2) density of egg gallery, and (3) density of beetle ood. Six sample units were superimposed in nested shion at each sample locus. Four of these were ctangular—0.1 ft^2 (93 cm^2); 0.25 ft^2 (232 cm^2); 0.5 ft^2 65 cm^2); and a sample proportional to tree diameter. he other two sample units were circular—0.1 ft^2 3 cm^2) and 0.25 ft^2 (232 cm^2). Each tree was sampled n the north and south aspects at breast height (4.5 ft · 1.4 m), 5 ft (1.5 m) below the top of the infestation, nd midway between these points. Ten trees in each of e following d.b.h. classes were sampled in each study lot: 6 to 8.9, 9 to 11.9, 12 to 14.9, and greater than 15 nches (15.2 to 22.6; 22.9 to 30.2; 30.5 to 37.9; and reater than 38.1 cm).

Analysis of variance showed statistically significant ifferences among sample sizes, tree diameters, and udy plots for attack and egg gallery densities, but owed no significant differences among sample sizes for rood density. Also, no differences occurred among sam- le heights for attack density; and only the middle and p sample heights differed significantly for brood den- ty (tables 1, 2, 3).

The variances of attack, egg gallery, and brood densi- es were generally greater at breast height and mid- eight than at the top. Overall, variance tended to be reatest at breast height, but since the mean values also nded to be larger at breast height, the coefficients of ariation were not correspondingly high.

The larger the sample size, the fewer zero counts were corded. Hence, the variance was more likely to be duced. However, considering that the reduction in vari- nce was rather minimal as sample size increased for attack, gallery, and brood densities, 0.25 ft^2 (232 cm^2) appears to be an acceptable sample size.

There was never complete consistency among aspects on the trees by plots. Therefore, random placement of samples by aspect was used.

The number of samples (trees) needed for a 20 percent standard mean error (SME) at the two-thirds probability level was computed for each sample size and all three variables at d.b.h. The north and south samples were combined because they were not random with respect to each other and in effect constituted a single sample. More samples are required for measuring attack density and gallery lengths for the smaller size sample than for the larger size. For measurements of brood density, the required number of samples decreased as sample size increased. Combining north and south samples at d.b.h. generally effected an increase in number of trees needed (table 4).

Sampling can be limited to the breast height region within infested trees and satisfy the requirements of efficiency and reliability in reproducing the characteristics of the population (Carlson and Cole 1965). In adhering to the principle of systematic random sampling, the sampling universe is defined as that subpopulation within a zone 1 ft (30.5 cm) above and 1 ft below breast height of infested trees. This zone was divided into four quadrants: north, east, south, and west. Using the 0.25-ft^2 (232-cm^2) sample, the zone was divided into four levels of 6 inches (15.2 cm) each, producing 16 sample loci. At each sampling date, two loci were selected at random for sampling without replacement. This plan for computing within-tree and among-tree variances allows for the determination of statistical distribution of the data.

Knight (1959) compared samples of mountain pine beetle progeny from different heights in ponderosa pine. He found that progeny numbers were fairly uniform

able 1.—Analysis of variance for attack density per 1 ft^2 (930 cm^2) of bark

Source	Sum of squares	Degrees of freedom	Mean square	F
lots	10,668.95	1	10,668.95	26.56**
ree sizes	12,887.36	3	4,295.79	10.70**
ample sizes	107,007.54	5	21,401.51	53.29**
T	1,776.20	3	592.07	1.47
S	2,491.72	5	498.34	1.24
S	7,241.00	15	482.73	1.20
rror, PTS	6,020.75	15	401.38	
Subtotal	148,093.52	47		
spects	0.49	1	0.49	0.00
evels	2,264.04	2	1,132.02	3.26*
L	411.86	2	205.93	.59
P	1,530.43	1	1,530.43	4.41*
T	2,087.41	3	695.80	2.00
S	1,066.13	5	213.23	.61
P	3,727.52	2	1,863.76	5.37*
T	2,949.48	6	491.58	1.42
S	2,327.64	10	232.76	.67
rror, PTSAL	72,296.93	208	347.58	
Total	236,755.45	287		

*Significant at 0.05 level of probability.
**Significant at 0.01 level of probability.

Table 2.—Analysis of variance for mountain pine beetle egg gallery density per $^1/_{10}$ ft^2 (93 cm^2) of bark

Source	Sum of squares	Degrees of freedom	Mean square	F
Plots	180.85	1	180.85	4.86*
Tree sizes	8,774.88	3	2,924.96	78.68**
Sample sizes	5,751.00	5	1,150.20	30.94**
PT	4,140.86	3	1,380.29	37.13**
PS	84.08	5	16.82	.45
TS	423.13	15	28.21	.76
Error, PTS	556.89	15	37.13	
Subtotal	19,911.69	47		
Aspects	1.41	1	1.41	0.00
Levels	1,800.34	2	900.17	1.71
AL	243.13	2	121.57	.23
AP	2,786.93	1	2,786.93	5.30*
AT	194.61	3	64.87	.12
AS	40.54	5	8.11	.02
LP	119.15	2	59.58	.11
LT	4,236.78	6	706.13	1.34
LS	668.63	10	66.86	.13
Error, PTSAL	109,753.61	208	527.66	
Total	139,756.82	287		

*Significant at 0.05 level of probability.
**Significant at 0.01 level of probability.

Table 3.—Analysis of variance for mountain pine beetle brood density per 1 ft^2 (930 cm^2) of bark

Source	Sum of squares	Degrees of freedom	Mean square	F
Plots (blocks)	370,909,825.92	1		
Sample sizes	12,845,676.64	3	4,281,892.21	1.16
Error, PS	11,038,342.64	3	3,679,447.55	
Subtotal	394,793,845.20	7		
Aspects	17,908,167.36	1	17,908,167.36	5.32*
Levels	35,517,526.09	2	17,758,763.04	5.27*
AP	44,466,345.09	1	44,466,345.03	13.20**
AS	1,774,537.12	3	591,512.37	.18
AL	33,448,518.07	2	16,724,259.04	4.96*
LP	19,075,248.37	2	9,537,624.51	2.83
LS	1,364,835.05	6	227,472.51	.07
Error, PSAL	77,471,934.61	23	363,344.98	
Total	625,820,956.90	47		

*Significant at 0.05 level of probability.
**Significant at 0.01 level of probability.

Table 4.—The number of mountain pine beetle-attacked trees required to be sampled for a 20 percent standard mean error at two-thirds probability level based upon summed north and south samples at breast height (rectangular samples only)

		Sample size			
Density	Plot	$^1/_{10}$ ft^2 (93 cm^2)	$^1/_4$ ft^2 (232 cm^2)	$^1/_2$ ft^2 (465 cm^2)	Proportional to d.b.h.
Attack	Teton	9.13	3.36	2.42	3.13
	Wasatch	7.76	4.22	3.63	3.08
Gallery	Teton	6.40	5.71	5.56	4.67
	Wasatch	2.46	2.63	2.20	2.12
Brood	Teton	8.19	9.93	8.16	7.56
	Wasatch	54.06	66.94	67.84	55.36

Note: Number of trees to be sampled should be rounded to nearest whole number for application.

roughout the infested portion of the tree trunk until pril. By July survival was somewhat higher in the wer bole. He concluded that counting beetles in 50 mples, two 6- by 6-inch (232-cm²) samples from each of trees, gave reliable estimates of beetle numbers per uare foot. The samples could be taken from the lower le, 4 to 7 ft (1.2 to 2.1 m) above ground because pulation fluctuations at that point were similar to ose in the upper bole. Populations of beetles in the insted trees in the fall and April were unrelated to instation trend. However, populations on the same trees July before the beetles emerged were directly related infestation trend.

Sequential sampling.—Sequential sampling involves a xible sample size instead of the fixed size required by nventional sampling. A number of units are examined til the cumulative number of beetles allows the instation to be classified as increasing, decreasing, or atic. Knight (1960) developed a sequential sampling an for mountain pine beetle in ponderosa pine. Sequenal sampling is not a research tool, but rather was deloped for making biological evaluations. In order for festation class limits to be developed, sampling of any infestations over several years is required so that pulation numbers can be related to changes in infestaon status (Knight 1967).

The least work is required where population levels are tremely low or extremely high. Sequential sampling sually saves considerable effort by preventing oversamling. However, in infestations where a static condition indicated, sampling may exceed that for a fixed size nventional method. Knight's (1960) sample was based n 0.25-ft² (232-cm²) samples, two from each infested ee. An upper limit of 80 samples was specified so that an infestation had not been classified by the time 80 amples were taken, the infestation was classified into he higher category. An error of classifying an infestaion too high was considered more acceptable than clasifying one too low.

Individual egg gallery sampling.—Biologically, it is of terest to know not only the densities of insects for a nit of space, but also the basic insect unit (individual, amily, cluster) of a population. A technique to find such nformation is based on sampling individual egg galleres, each of which can be considered a "single family."

The pattern of egg deposition within a gallery and the istance between galleries set the stage for competitive nteractions of larvae within and between egg galleries. n the past, we have based the intensity of competition pon the number of attacks per square foot (930 cm²). owever, sampling of individual egg galleries and their roximity to other egg galleries may give a better measre of competitive interactions (Cole 1967). The single allery unit of measurement assumes that the effect of n ecological event on a "family unit" is representative f what would happen in an entire population that exerienced a similar event.

Two generations (1965 and 1966) of the mountain pine eetle were sampled on three areas: Caribou, Teton, and Wasatch National Forests. Each generation was sampled three times—fall, spring, and summer—and, therefore, included counts of prewinter eggs and immature larvae, postwinter mature larvae, and mature larvae and pupae, respectively. The attack density and gallery length were also measured. Two sample units were taken from each of four trees, within each of three diameter classes—9, 12, and 15 inches (23, 30.5, and 38 cm) d.b.h. (table 5). Results obtained from sampling individual egg galleries were compared to those obtained from 0.25-ft² (232-cm²) area samples (Cole 1970). Data from the 0.25-ft² samples were recorded in three ways: (1) average brood per 0.25 ft²; (2) average brood per attack; and (3) average brood per inch (2.54 cm) of egg gallery.

Percentage of larval survival (table 6) was rather consistent in all measurement units, regardless of when the data were taken during the beetles' development. The less consistency and generally higher survival within the 15-inch (38-cm) diameter class are probably attributable to the increased attack density and the greater food quantity (phloem thickness) than found in 9- and 12-inch (23-cm and 30.5-cm) trees.

The encouraging aspect of these survival rates is their general similarity. Thus, one could use a single unit, or combined measurement units, to estimate survival, particularly for life table studies, and be reasonably assured of maintaining congruity between life stages. The information desired by the sampler, and time of year, will determine the selection of a measurement unit.

The single gallery sample provided the most representative data of the entire population but required additional biological measurement of attack density. Brood data from the 6- by 6-inch (232-cm²) sample taken on an attack density basis provided the most statistically reliable information and encompassed the pertinent biological information. Percent survival, as could be used in elementary life tables, was rather consistent in all measurement units, regardless of when sampling occurred in the beetle's life cycle.

Radiographic sampling.—Following a cohort of bark beetles through development would be more desirable than obtaining sample estimates from different cohorts. Radiography makes possible such study of cryptic forest insects and has proved valuable in studying laboratory populations of bark beetles (Johnson and Molatore 1961; Berryman and Stark 1962). In addition, radiography has been used in the study of field populations by taking bark samples containing western or southern pine beetles into the lab for radiographing (DeMars 1963; Fatzinger and Dixon 1965). X-radiography was tried in seeking more accurate methods of sampling mountain pine beetle brood and their mortality factors.

In laboratory studies, results from radiographs of mountain pine beetle in infested bark and wood slabs varying in thickness from 1.5 to 2 inches (3.8 to 5.1 cm) showed that:

1. X-ray exposure adjusted for small differences in thickness and moisture content of wood and bark could yield readable radiographs.
2. An x-ray setting of 25 kilovolts (KV) was best when using the radiographs for counts of small- and medium-sized larvae. Either 25 or 45 KV could be used when radiographs were used to obtain counts of large larvae, pupae, and teneral adults.

Table 5.—Estimated means and standard deviations of mountain pine beetle brood units by diameter class, by season, and by measurement unit (years pooled)

Diameter class	Observation	Measurement unit[1]	Sample size	Estimated standard deviations: Among units within trees	Among units	Among unit totals	Mean
Inches			*(n)*	*(Sw)*	*(Su)*	*(Sy)*	*(y)*
9 (23 cm)	Fall	Single gallery	36	20.5	9.8	2.5	19.0
		B[2]	46	27.1	20.6	5.9	55.4
		BA	46	15.4	5.5	4.4	20.2
		BI	46	2.5	1.3	.2	2.8
	Spring	Single gallery	48	13.7	4.1	2.1	9.4
		B	46	18.9	17.9	4.7	19.0
		BA	46	11.1	7.2	2.2	6.1
		BI	46	1.2	.6	.1	1.0
	Summer	Single gallery	48	8.9	3.7	1.0	3.5
		B	48	11.7	4.4	1.4	11.0
		BA	48	4.5	1.7	.5	3.3
		BI	48	1.0	.6	.1	.6
12 (30.5 cm)	Fall	Single gallery	36	16.6	9.5	1.6	21.9
		B	40	64.1	39.5	4.9	67.8
		BA	40	15.9	8.5	3.2	21.6
		BI	44	2.4	1.3	.2	2.9
	Spring	Single gallery	40	7.1	1.8	1.0	7.3
		B	40	14.9	5.8	2.7	17.3
		BA	40	7.6	4.2	.8	5.0
		BI	40	.9	.5	.1	.7
	Summer	Single gallery	40	8.6	3.5	1.1	2.5
		B	40	8.9	3.3	1.2	12.4
		BA	40	3.4	.8	.6	3.7
		BI	40	.8	.4	.1	.4
15 (38 cm)	Fall	Single gallery	36	13.8	5.3	1.9	9.5
		B	36	41.3	12.3	5.2	35.1
		BA	36	13.5	7.1	1.4	8.3
		BI	38	1.7	1.0	.1	.7
	Spring	Single gallery	36	13.8	5.3	1.9	9.5
		B	36	23.5	14.3	5.2	35.1
		BA	36	10.9	4.9	1.4	8.3
		BI	38	1.1	.6	.1	.7
	Summer	Single gallery	36	3.4	2.4	.8	3.7
		B	36	6.2	8.8	2.3	20.8
		BA	36	2.8	2.3	.7	5.1
		BI	38	1.0	.5	.1	.6

[1] $6 \times 6 = \frac{1}{4}\ ft^2 = 232\ cm^2$.

[2] B = brood × (6- by 6-inch area).

BA = brood per attack on a 6- by 6-inch area.

BI = brood per inch of egg gallery on a 6- by 6-inch area.

3. Errors in estimating and identifying stages of the beetles from radiographs taken at 25 KV were less than 10 percent of the mean, thus yielding estimates acceptable for population studies of bark beetles.

4. Estimates of egg gallery length could best be taken when larvae were small because extensive mining by the time larvae are mature obscures some of the egg gallery.

5. Attack density of parent adults can be determined from radiographs taken during any stage of beetle development (Amman and Rasmussen 1969).

Techniques developed during laboratory studies were then tested under field conditions (Amman and Rasmussen 1974).

Unlike larvae of the western and southern pine beetles, which spend much of the developmental period in the outer bark, mountain pine beetle larvae in the thin bark of lodgepole pine feed and pupate primarily in the phloem layer against the sapwood surface. Consequently removal of bark samples for radiographing would also expose larvae for direct counting. Therefore, any advantage of using the radiographic method in the field would be in the accuracy and speed of sampling beetles *in situ* and to follow the same cohort through to adult emergence.

A chain saw was used to cut two vertical slots into the trunk of each tree for film placement. This procedure resulted in a "slab" up to 2 inches (5 cm) thick, approximately 30 inches (75 cm) above ground level; slots were located at random with respect to cardinal direction. Slots were used because radiographing the entire tree would (1) superimpose images of broods from the near side upon those on the far side, (2) require a much ble 6.—Percent of mountain pine beetle larval survival as estimated by measurement unit

ameter lass	Measurement unit[1]	Larval survival from Fall to spring	 Spring to summer	 Fall to summer	Average attack density per diameter class
ches		*Percent*			
(23 cm)	Single gallery	49.58	36.90	18.30	3.04
	B[2]	34.28	58.16	19.94	
	BA	30.11	54.37	16.37	
	BI	35.13	62.24	21.86	
(30.5 cm)	Single gallery	33.12	33.75	11.18	3.37
	B	25.54	71.81	18.34	
	BA	23.19	74.05	17.18	
	BI	24.91	60.56	15.09	
(38 cm)	Single gallery	46.57	38.38	17.87	4.04
	B	46.10	59.22	27.30	
	BA	74.98	61.10	45.81	
	BI	31.86	81.94	26.11	

[1] 6 × 6 = $^1/_4$ ft^2 = 232 cm^2.
[2] B = brood × (6- by 6-inch area).
BA = brood per attack on a 6- by 6-inch area.
BI = brood per inch of egg gallery on a 6- by 6-inch area.

reater exposure time, and (3) result in radiographs of ow contrast. The slots were about 8 by 10 inches (20 by 5 cm), to accommodate film of that size in individual ackets, and were open only on one side in the larger rees to slow the rate of tissue drying. In the smaller rees, the trunk was not large enough to keep one side of he slot closed; consequently, slots were open on both ides. However, all slots were sealed with caulking cord o slow the rate of drying between sample dates.

An evaluation of the radiographic method of sampling nountain pine beetle populations was based on both statistical and operational considerations. Estimates vere compared with those obtained from the same trees, sing the bark-removal method of Carlson and Cole 1965).

Assuming negligible location effects, no significant lifference at the 0.05 level of probability was revealed among population estimates obtained by using either the bark-removal method or estimates made from radiographs for any of the three sample dates (table 7). One source of difference was noted between estimates obtained by the two methods for the first sample: eggs could be counted in bark samples, but not on radiographs. As observed previously (Amman and Rasmussen 1969), radiographing mountain pine beetles through wood precluded detection of the slight difference in density of eggs. Eggs of the western pine beetle have been seen on radiographs when only bark was radiographed (DeMars 1963). The authors detected no significant difference between methods for estimates of egg gallery nor of gallery starts. Therefore, estimates from radiographs appear to be comparable to those obtained by bark-removal sampling (Carlson and Cole 1965).

able 7.—Comparison of estimates of mountain pine beetle brood density, gallery lengths, and gallery starts from bark-removal and radiographic sampling

	Bark-removal sampling	Radiographic sampling[1]	Significance
	Average/ft^2 (930 cm^2)		
rood number:			
Observation 1	215.5	177.5	$P > 0.10$
Observation 2	83.2	78.3	$P > 0.10$
Observation 3	48.2	40.6	$P > 0.10$
allery (cm)	261.1	238.3	$P > 0.10$
allery starts	10.0	8.9	$P > 0.10$

[1] Estimates made by two observers were averaged and the average was compared with the estimates obtained by bark-removal sampling.

Comparisons of estimates made from radiographs by the two observers revealed no significant difference for beetle populations and egg gallery (table 8). However, the observers gave significantly different estimates for the numbers of gallery starts ($P<0.01$). Overall, observer differences were small, and adequately trained observers can be expected to give comparable estimates from radiographs.

The bark-removal method was almost 2.5 times faster than the radiographic method. Costs were proportional to time—$1 per sample using the bark-removal method and $2.50 per sample using the radiographic method (1974 costs).

A major disadvantage of the radiographic method was the inability to assess mortality from the radiographs. Some predators could be seen and counted on the radiographs. The only one of consequence was *Medetera aldrichii* Wheeler (Diptera: Dolichopodidae). Dead beetles that had dried completely were not often detected; usually those that were could not be assigned to specific causes of mortality. In addition, larvae that had died recently but still contained much moisture could not be distinguished from living larvae. The bark-removal sampling technique is definitely superior in this respect, because the cause of death of most larvae can be determined. Consequently, the bark-removal sampling method will continue to be the choice for life table sampling of mountain pine beetles in lodgepole pine where assessment of mortality factors is of primary concern.

MODELING

A mathematical model should contain the essential relations under study. The success of the model depends upon whether those factors included are really essential to the explanation. Biological entities are so complex that it is impossible to choose more than a fraction of all factors for study. The study of a few carefully selected factors can lead to improved understanding of the relations under study and provide leads for subsequent investigations. However, the study of too few factors for too short a time can lead to misinterpretations. Conceptual or theoretical models give clues to modes of behavioral interactions and may point toward important population characteristics. Empirical models give an accounting of these facets. In either case, if the model is to be used as a measurement tool, the nature or mode of operation of the biological unit must be thoroughly understood to correctly interpret these components in terms of population dynamics.

Models are simplifications of reality. A model, howev simple, should be an accurate representation of that re ity. Were it to be complete in every detail, it then wou be equivalent to real life. Ultimately, it is the closeness of agreement between the model and the real system—the validation of the model—that determines its usefulness. It is futile and useless to test the model with dat used in its construction or to conceptualize without verification. Only through further experimentation can discrepancies between predicted and measured behavio be resolved or minimized.

Both conceptual and predictive models are found in mountain pine beetle literature. Models discussed here will be limited to those not previously discussed in par I and II of this monograph on mountain pine beetle. Parts I and II contain most of the two- and three-dimensional models of beetle, host, or beetle-host interactions.

The models in this publication have to do with the interactions of stands and beetle populations and are presented in an order consistent with the life cycle of th beetle.

Beetle Life Table Models

The life table is one of the oldest, most useful, and best known expressions in the field of population studies. Deevey (1947) defined it as succinctly and clearly as anyone: "A life table is a concise summary of certain vital statistics of a population." Therefore, the life table approach was used to determine the principal factors affecting natality and mortality of mountain pin beetle.

The life tables were based on intensive population sampling from annually established plots within both high and low level populations of the beetle. These data have been supplemented with detailed studies in both field and laboratory.

Data for life tables.—The observation times and the types of data collected were:

1. N_E = egg density. This is the first observation taken when the flight and attack period of the parent adult beetle is reasonably completed and the majority o egg deposition accomplished. The data needed from this observation are number of attacks, number of egg niche and larval starts, number of small larvae, and length of egg gallery.

Table 8.—Comparison of observer estimates of mountain pine beetle brood densities, gallery lengths, and gallery starts made independently from the same set of radiographs

	Observer 1	Observer 2	Significance
	Average ft² (930 cm²)		
Brood number:			
Observation 1	171.5	183.5	$P > 0.05$
Observation 2	82.9	73.6	$P > 0.10$
Observation 3	45.2	36.0	$P > 0.10$
Gallery (cm)	234.4	242.1	$P > 0.10$
Gallery starts	6.3	11.5	$P < 0.01$

2. N_1 = brood density prior to winter. This observa- t n is taken as close to the onset of winter as possible. ta from this observation should include additional at- ks and egg deposition and small larvae density.

3. N_2 = brood density immediately postwinter (April). is observation determines winter kill and includes th small and possibly large larvae density.

4. N_3 = late spring brood density (May). Data will in- ide small and large larvae and possibly pupae densi- s. This and N_4 are the more important observations. critical population changes occur, they will begin to ow during these stages.

5. N_4 = early summer brood density (June). The scription of N_3 suffices for this observation.

6. N_5 = late summer brood density (July). Large lar- e, pupae, and callow adult densities are included.

7. N_{na} = emerging new adults. This observation is a mple of emerging adults and represents brood sur- val. The caging can be done at any time after N_4 and ior to flight.

These seven observations are probably the ideal for a mplete life table. However, we found suitable life ta- es could be constructed by combining and omitting ob- rvations. We settled on the following observations:

1.	Late fall:	The population surviving the egg stage and entering the winter period as second and third instar larvae ($N_E + N_1$).
2.	Spring:	The population surviving winter and containing the third and fourth instar larvae (N_2).
3.	Summer:	The population containing the mature larvae and pupae ($N_3 + N_4 + N_5$).
4.	Emerging adults:	The final surviving population estimates of emerging adults obtained by caging a 6- by 6-inch (232-cm^2) area of bark (N_{na}).

Using life tables.—Life tables can demonstrate population trend. Examples of decreasing and increasing populations are shown in tables 9 and 10. The importance of N_3 and N_4 is shown in comparison of M_x (mortality occurring during interval x) for these respective age intervals. If, during N_3, the brood loss due to MF_2 (mortality factor in interval 2) increases only 0.85 larva, this can be great enough to almost halve the loss due to MF_4 (say, competition). In other words, a so-called beneficial predator could reduce the pressure from competition to the

ble 9.—Life table for a mountain pine beetle population showing a decreasing trend

x	N_x	M_xF		M_x	100 M/N
Age-interval	No. alive at start of x	Factor responsible for M_x		No. dying during x	M_x as percentage of N_x
$_0$ - adults	1 female				
$_E$ - eggs	100.00	MF_1		23.63	23.63
		MF_2		16.84	16.84
		MF_3		6.78	6.78
			Total	47.25	47.25
$_1$ - small larvae	52.75	MF_1		8.25	15.64
		MF_2		3.00	5.69
		MF_4		20.00	37.91
		MF_3		1.00	1.90
			Total	32.25	61.14
$_2$ - small larvae	20.50	MF_5		12.13	59.17
$_3$ - large larvae	8.38	MF_2		1.15	13.72
		MF_4		5.03	60.02
		MF_3		.45	5.37
			Total	6.63	79.11
$_4$ - large larvae pupae	1.75	MF_2		0.25	14.28
		MF_1		.15	8.57
		MF_4		.05	2.86
		MF_3		.05	2.86
			Total	0.50	28.57
$_5$ - pupae callow adults	1.25	MF_2		0.35	28.00
		MF_1		.30	24.00
		MF_3		.10	8.00
			Total	0.75	60.00
$_{na}$ - new adults	0.50	Brood mortality			99.50
females	.25	Generation mortality			75.00 (−)
N_{E+1}	25.00				

Table 10.—Life table for a mountain pine beetle population showing an increasing trend

x	N_x	M_xF	M_x	100 M/N
Age-interval	No. alive at start of x	Factor responsible for M_x	No. dying during x	M_x as percentage of N_x
N_o – adults	1 female			
N_E – eggs	100.00	MF_1	23.63	23.63
		MF_2	16.84	16.84
		MF_3	6.78	6.78
		Total	47.25	47.25
N_1 – small larvae	52.75	MF_1	8.25	15.64
		MF_2	3.00	5.69
		MF_4	20.00	37.91
		MF_3	1.00	1.90
		Total	32.25	61.14
N_2 – small larvae	20.50	MF_5	12.13	59.17
N_3 – large larvae	8.38	MF_2	2.00	23.87
		MF_4	2.80	33.41
		MF_3	.45	5.37
		Total	5.25	62.65
N_4 – large larvae pupae	3.13	MF_2	0.10	3.19
		MF_1	.07	2.24
		MF_4	.07	2.24
		MF_3	.01	.32
		Total	0.25	7.99
N_5 – pupae callow adults	2.88	MF_2	0.17	5.90
		MF_1	.15	5.21
		MF_3	.06	2.08
		Total	0.38	13.19
N_{na} – new adults	2.50	Brood mortality		97.50
females	1.25	Generation mortality		25.00 (+)
N_{E+1}	125.00			

extent that the population is released, and this in effect causes an increase in the generation trend. The end effect is an increase of 25 percent more female beetles emerging than attacked. This also points out the importance of caging for emerging adults to obtain the generation trend. Brood mortality differed by only 2 percent, yet generation mortality differed 100 percent. Five times more adult female beetles emerged in the second situation than in the first.

An additional column, S_x (survival rate within x), can be added to the life table at this time. The use of survivals rather than mortalities presents a more reasonable approach because it is the residual live populations that concern us most. An example is shown in table 11.

The accumulated life tables can now be used in a mathematical model to describe and define the causes of change. The analysis of the model is based on the age-interval survival rates (Morris 1963).

The model follows the form:

$$S_G = S_E \times S_1 \times S_2 \times S_3 \times S_4 \times S_5 \times P_F$$

where

N = population density of the mountain pine beetle per 0.25 ft^2 of bark area.

N_E, N_1 . . . N_3, N_{na}, N_{pa} represent eggs, brood densit by each of five observations, new adults and parent adults, respectively.

S_E = survival of eggs to eclosion = N_1/N_E.

S_1 = fall survival of brood from observation 1 to observation 2 = N_2/N_1.

S_2 = winter survival of brood = N_3/N_2.

S_3 = late spring survival of brood = N_4/N_3.

S_4 = early summer survival of brood = N_5/N_4.

S_5 = late summer survival of brood = N_{na}/N_5.

P_F = the average proportion of fecundity of the adult female population at the current attack density; extent of egg deposition is inversely proportional to attack density.

S_G = survival in any generation (equation 1).

ble 11.—Survival rates for mountain pine beetles and computed generation survival estimated from tables 9 and 10

ife ble	x Age-interval	No. alive at start of x	N_{x+1}/N_x	S_x Survival rate within x
1	N_E	100.00	N_1/N_E	0.528
	N_1	52.75	N_2/N_1	.389
	N_2	20.50	N_3/N_2	.409
	N_3	8.38	N_4/N_3	.209
	N_4	1.75	N_5/N_4	.714
	N_5	1.25	N_{na}/N_5	.400
	N_{na}	.50		$S_G = 0.005$
2	N_E	100.00		0.528
	N_1	52.75		.389
	N_2	20.50		.409
	N_3	8.38		.374
	N_4	3.13		.920
	N_5	2.88		.868
	N_{na}	2.50		$S_G = 0.025$

Simple regressions are used and examples of their atistics are listed in table 12. S_G is the dependent varile and the terms S_E . . . P_F independent variables. ransformation of the data, S_E . . . P_F, to common logs necessary to provide for a linear additive model. The ta are also coded by 10,000 to avoid negative garithms. Thus, equation 1 becomes:

$$\text{Log } 10{,}000\ S_G = \text{Log } 10{,}000\ S_E + \ldots + \text{Log } 10{,}000\ P_7 \qquad (2)$$

The regressions are used to determine whether surival in any age interval is a key to determining generaon survival. If such occurs, then prediction of S_G can e possible from sampling the age interval(s) responsible for S_G. It follows then, to explain variation in S_G, we must explain the variation in the age interval(s) most responsible for that variation in S_G.

The determination of the variation within S_3 and S_4 could be the next step. Meanwhile, correlations and regressions can be computed for age intervals and generation survivals and for the parasite-predators within their respective age intervals. The latter regression can be used to determine which, if any, biotic agents are causing the variations, thus improving the evaluation of an infestation by explaining and predicting its trend and recommending the application and timing of control measures.

able 12.—Example of regression statistics for a mountain pine beetle generation survival model. Mean survival for observation, $\bar{x}$; coefficient of determination, r^2; correlation coefficient, r; intercept, a; slope, b (scaled by 10,000)

Area	Observation	$\bar{x}$	r^2	r	a	b
asatch	S_E	0.521	0.004	−0.06	2.44	−0.18
	S_1	.197	.457	−.68	4.98	−.97
	S_2	.492	.021	.14	1.07	.20
	S_3	.871	.967	.98	−1.20	.75
	S_4	.355	.999	−.99	5.29	−.99
	S_5	.834	1.000	1.00	−3.33	1.30
	P_F	.458	.723	.85	−7.42	2.51
	(S_G = 0.005964)					
eton	S_E	.621	.741	−.86	29.04	−7.11
	S_1	.425	.940	.97	.79	.36
	S_2	.461	.955	.98	.84	.34
	S_3	.696	.332	.58	−3.20	1.38
	S_4	1.965	.921	−.96	22.83	−4.83
	S_5	.216	.918	−.96	10.67	−2.57
	P_F	.337	.000	−.01	2.57	.14
	(S_G = 0.012113)					

During the last 2 of the 3 years of study, the mountain pine beetle parent adult female either elongated the egg gallery and resumed egg deposition, or emerged, flew, and reattacked infested trees, attacked new trees, or both. This phenomenon was more pronounced and in greater consequence on the Teton plots (S_4 $\bar{x} = 1.965$) than on the Wasatch plots (S_3 $\bar{x} = 0.871$). The addition of new brood (almost double) halfway through the life cycle overcame the effect of the reduction factors to the extent the number of emerging adults was almost equal to the number of eggs deposited in S_E. Consequently, the correlation coefficients are high for the Teton, $S_E \ldots S_5$.

An analysis of variance was done to compare the effects of plots and year (table 13).

Table 13.—Variance of mountain pine beetle survival in each age-interval. Plot and year are main sources of variation (transformed data)

Survival	Source of variation	Both plots	Wasatch	Teton
S_E	Plots	0.00877		
	Years	.00648	0.02171	0.017830
S_1	Plots	.16616		
	Years	.00055	.08691	.016507
S_2	Plots	.00117		
	Years	.34743	.10303	.149240
S_3	Plots	.01427		
	Years	.01707	.30640	.212630
S_4	Plots	.83865		
	Years	.10859	.18339	.047950
S_5	Plots	.51536		
	Years	.13860	.11429	.168470
P_F	Plots	.02656		
	Years	.04917	.02082	.013460
S_G	Plots	.14950		
	Years	.90938	.18203	1.214610

The Wasatch infestation was, in fact, decreasing with respect to number of host trees infested each year. However, attack density and egg deposition were greater on the Wasatch than on the Teton plots. The mortality within any one generation had been as expected for the Wasatch (decreasing trend), but for the Teton (explosively increasing), the generation mortality percentage had been less than the survival percentage (more adults emerging than attacked) (table 14).

Table 14.—Comparison of mountain pine beetle population trends for attack density and egg deposition per square foot of bark, and mortality and survival percents by years at two locations

Area	Year	Attack density	Egg deposition	Mortality (−) survival (+)	
				Egg to adult	Adult to adult
				Percent	
Wasatch	1961	28.1	800	99(−)	89(−)
	1962	24.0	1,035	94(−)	63(−)
	1963	16.0	1,027	97(−)	73(−)
Teton	1961	14.1	306	69(−)	225(+)
	1962	15.0	545	[1]99(−)	[1]98(−)
	1963	15.0	598	71(−)	278(+)

[1] Catastrophic winter kill—highly localized over plot area.

For either infestation, the greatest variation in SG is probably to S_3 or S_4 (table 12). Hence, these are the observation times for intensive work to determine factors of change. Inferences from table 13 are:

$S_E \ldots S_2$ —Small, consistent, or low magnitude contributed variance, except S_2 between years. This is due to the catastrophic winter kill during 1962, Teton (table 14).

S_3 —Contributed variance of little consequence. However, resumption of attacks and egg deposition probably obscured the real magnitude.

S_4 and S_5 —Reattacks and egg deposition in full activity and more pronounced on the Teton. Thus, the higher contributed variance by plots.

P_F —Fecundity remained fairly constant for sources concerned.

Some correlations between parasite-predator densities and age-interval survivals were computed. For most parasite-predator groups the correlation coefficients remained stable for each age interval. However, for *Medetera* the correlation was quite low except for the Wasatch S_4 where the degree of correlation increased slightly. In this situation, the Wasatch had consistently shown a higher percentage of *Medetera*. The age interval S_4 had been the point of separation between the two populations with respect to generation mortality/survival ratios.

The analysis of age-interval survivals in relation to generation survival had certain preliminary value and gave considerable insight during the early stages of our research.

Abridged cohort life tables.—The abridged cohort life table, in which a generation of beetles is sampled at particular points in time, was used thereafter in this study (Chiang 1968). In its strictest form, a cohort life table is a record of the actual mortality experienced by a given group of individuals over a period extending from birth of all individuals until death of the last member of that group. However, death of the last member in this case was not necessarily recorded. Rather, the emergence of he adult beetle was equated as the end of life for that particular cohort. Thus, mortality during the flight eriod was not recorded.

The ideas and procedures used in the construction of he abridged cohort life table are the same as those used in the construction of the complete life table except for ifferences that result from the length of intervals.

Table 15, an example of an abridged cohort life table sed, is explained in detail:

Column 1. Diameter at breast height (d.b.h.) for three roups of trees in which mountain pine beetle were sampled. Observation numbers correspond to: 1 is early fall; is late fall; 3 is early spring; 4 is early summer; and 5 s late summer (newly emerged adults).

Column 2. Age interval (x_i to x_{i+1}). Each interval is efined by the two ages stated except for the final age interval, which ends with the emergence of the adult eetle.

Column 3. Number alive at age x_i, l_i. Totaling the umber alive, dead, and for all stages gives a base popuation, l_0. Thereafter, survivors per sampling time will omprise l_i.

Column 4. Number dying in interval (x_i to x_{i+1}), d_i. hese are the actual counts of dead individuals at the ime of sampling. The number dying is derived by subraction: $l_i - l_{i+1}$. If actual counts are used, then sampling error must be taken into account; high sampling rrors can be the reason for an apparent increase n population from l_i to l_{i+1}.

Column 5. Proportion dying in interval (x_i to x_{i+1}), $\hat{q}_i$. Each $\hat{q}_i$ is an estimate of the probability that an individual alive at the age x will die during the interval x_i to x_{i+1}). $q_i = \frac{d_i}{l_i}$

Column 6. Proportion surviving in interval (x_i to x_{i+1}), p_i. Each p_i is an estimate of the probability that an individual alive at age x will survive during the interval (x_i to x_{i+1}). $\hat{p}_i = 1-\hat{q}_i$.

Column 7. Variance of proportion dying during the interval is equal to the variance of proportion surviving during the interval.

Column 8. The length of the typical ith interval in this particular abridged life table is dependent upon the sampling interval, which is neither uniform in length for all intervals nor longer than a few months. The essential element here is the average fraction of the interval lived by each beetle that dies at an age included in the interval. This fraction is denoted by a_i. The assumption of $a_i = 0.5$ for each time unit of age within an interval (x_i to x_{i+1}) does not necessarily imply that $a_i = 0.5$ for the entire interval. The value of the fraction a_i depends on the mortality pattern over an entire interval, but not on the mortality rate for any single generation. When the mortality rate increases with age in an interval, the fraction $a_i > 0.5$; when the reverse pattern prevails, $a_i < 0.5$. In our particular case, the fraction a_i was necessarily taken to be 0.5 of the sampling interval, because time of death within the sampling interval or interval lived was not measured.

Column 9. Number of time units lived in interval (x_i to x_{i+1}), L_i. Each member of the cohort who survives the interval (one generation year) contributes one interval to L_i, while each member who dies during the interval contributes, on the average, a fraction a_i of that interval where a_i is assumed to be 0.5.

$$L_i = n_i\ (l_i - 0.5\ d_i)$$

able 15.—Example of an abridged cohort life table for mountain pine beetle. Detailed descriptions are in text

1 D.b.h./ obs.	2 Age interval (days)	3 No. living at age x_i	4 No. dying during interval	5 Proportion dying during interval	6 Proportion surviving interval	7 $V_{q_i} = V_{p_i}$	8 Average fraction of last age interval	9 Number of time units lived in interval	10 Total time units lived beyond age x_i	11 Obs. E (life) at age x_i	12 S.E. e_i
	x_i to x_{i+1}	l_i	d_i	q_i	P_i		a_i	L_i	T_i	e_i	
23 cm											
1	30	3,079	325	0.1056	0.8944	0.000031	0.50	87,495	633,540	212.748	1.450
2	180	2,754	958	.3479	.6521	.000082	.50	409,500	546,045	206.084	.997
3	60	1,796	676	.3764	.6263	.000131	.50	87,480	136,545	88.004	.906
4	30	1,120	403	.3598	.6402	.000206	.50	27,555	49,065	63.013	.868
5	60	717	717	1.0000	0		.50	21,510	21,510	60.000	0
30 cm											
1	30	3,309	633	.1913	.8087	0.000047	0.50	89,775	600,345	187.937	1.609
2	180	2,676	1,074	.4013	.5987	.000090	.50	385,020	510,570	198.845	1.058
3	60	1,602	598	.3733	.6267	.000146	.50	78,180	125,550	91.816	.995
4	30	1,104	286	.2849	.7151	.000203	.50	25,830	47,370	68.635	.862
5	60	718	718	1.0000	0		.50	21,540	21,540	60.000	0
38 cm											
1	30	2,936	670	.2282	.7718	0.000060	0.50	78,030	523,600	184.363	1.804
2	180	2,266	815	.3598	.6403	.000102	.50	334,530	445,570	204.440	1.110
3	60	1,451	546	.3763	.6237	.000162	.50	70,780	111,040	88.718	1.016
4	30	905	312	.3448	.6552	.000250	.50	22,470	40,260	64.144	.958
5	60	593	593	1.0000	0		.50	17,790	17,790	60.000	0

Column 10. Total number of time units lived beyond age x_i, T_i. This total is equal to the sum of the number of time units lived in each age interval beginning with age x.

$$T_i = L_i + L_{i+1} + L_{i+2} + \ldots + L_w$$

Column 11. Observed expectation of life at age x_i, $\hat{e}_i$. This is the average number of time units yet to be lived by an individual now age x_i. Because the total number of time units of life remaining to the l_i individuals is T_i,

$$e_i = \frac{T_i}{l_i}, \; i = 0, 1, \ldots, w$$

Each $\hat{e}_i$ summarizes the mortality experience of individuals beyond age x_i in the cohort population under consideration, making this column very important in the life table. Furthermore, this is the only column in the table other than q_i and a_i that is meaningful without reference to the starting population, l_0. As a rule, the expectation of life, $\hat{e}_i$, decreases as the age, x_i, increases (with the single exception of the first interval of life, when the reverse is true due to high mortality during that interval). The symbol, $\hat{e}_i$, denoting the observed expectation of life, is computed from the actual mortality data and is an estimate of $\hat{e}_i$, the true unknown expectation of life at age x_i.

Column 12. Sampling error of life expectation at age x_i.

Sample variance of (1) the proportion $\hat{q}_i$ of individuals dying in an interval (x_i, x_{i+1}), (2) the proportion $\hat{p}_{ij}$ of individuals alive at age x_i who will survive to age x_j, and (3) the observed expectation of life $\hat{e}_\alpha$, at age x_α, can be computed in the following manner:

In a cohort life table, the proportions $\hat{q}_i$ and $\hat{p}_i$ are computed directly from

$$\hat{q}_i = \frac{d_i}{l_i} \text{ and } \hat{p}_i = \frac{l_i + 1}{l_i}$$

and are ordinary binomial proportions with the sample variance

$$S\hat{p}_i^2 = \frac{l}{l_i}[p_i q_i]$$

The proportion $\hat{p}_{ij}$ of survivors is a general form of $\hat{p}_i$ and is equal to $\hat{p}_i$ when $j = i + 1$. Corresponding to the sample variance of $\hat{p}_{ij}$ is

$$S^2\hat{p}_{ij} = \frac{l}{l_i}[\hat{p}_{ij}(1 - \hat{p}_{ij})], \; i>j, \; j = 0, 1, \ldots n$$

The $\hat{p}_i$'s are linearly uncorrelated, and therefore the sample variance of $\hat{p}_{ij}$ also has the form

$$S^2\hat{p}_{ij} = \hat{p}_{ij}^2 \sum_{h=i}^{j-1} \hat{p}_h^{-2} \, S\hat{p}_h^2$$

Let Y denote the future lifetime of an individual at age x_α; the observed expectation of life $\hat{e}_\alpha$ is simply the same mean $\overline{Y}_\alpha$ of the l_α values of Y, or

$$\hat{e}_\alpha = \overline{Y}_\alpha$$

These values of Y are recorded in the life table in the form of a frequency distribution in which d_i is the frequency in the interval (x_i, x_{i+1}), $i = \alpha, \alpha+1, \ldots, w$. On the average, each of the d_i individuals lives x_i time units plus a fraction of α_i of the interval (x_i, x_{i+1}), or $x_i - x_\alpha + \alpha_i n_i$ time units beyond x_α; that is, for each of the d_i individuals,

$$Y_\alpha = x_i - x_\alpha + \alpha_i n_i, \; i = \alpha, \alpha+1, \ldots, w$$

In this case, n_i is the length of the typical ith interval i an abridged table, or $n_i = x_{i+1} - x_i$, which is greater than one time unit.

The sample mean of Y_α can then be expressed as

$$\hat{e}_\alpha = \overline{Y}_\alpha = \frac{1}{l_\alpha} \sum_{i=\alpha}^{w} (x_i - x_\alpha + \alpha_i n_i) d_i$$

and the sample variance of Y_α as

$$S^2Y_\alpha = \frac{1}{l_\alpha} \sum_{i=\alpha}^{w} [(x_i - x_\alpha + \alpha_i n_i) - \hat{e}_\alpha]^2 d_i$$

Therefore, the sample variance of the sample mean $\overline{Y}_\alpha$, or $\hat{e}_\alpha$, is given by

$$S\hat{e}_\alpha^2 = \frac{1}{l_\alpha} S^2Y_\alpha$$

or

$$S\hat{e}_\alpha^2 = \frac{1}{l_\alpha^2} \sum_{i=\alpha}^{w} [(x_i - x_\alpha + \alpha_i n_i) - \hat{e}_\alpha]^2 d_i$$

Beetle Life Stage Models

Using data obtained by sampling for life tables, survival of the various beetle stages was modeled in relation to lodgepole pine size, from endemic through the epidemic and postepidemic stages. Later, these data were linked by life stage to stand characteristics and stand mortality. These models portray smoothed insect density trends over years by life stage and size of infested tree.

Data analysis consisted of plotting brood densities fo each life stage over d.b.h. of the infested tree and observed year of the infestation. Data are presented on th basis of diameter rather than phloem thickness, the mai determinant of mountain pine beetle brood production, because much of the data through the main years of th epidemic were taken before recognition of the importanc of phloem thickness. However, the relation of phloem t diameter is firmly established (Amman 1969, 1975, 197 D. M. Cole 1973). Trends smoothed in accord with expe tation over both d.b.h. and year were established through these points. The resulting surfaces were described mathematically using techniques presented b Jensen and Homeyer (1970, 1971) and Jensen (1973). Th appendix contains FORTRAN statements of the mathematical descriptions (Cole and others 1976).

Each model was first developed graphically using expectation, known constraints, and apparent data trends in arriving at smoothed curve forms. These were fitted through the data by approximate "least deviations." Th resulting graphic forms were described algebraically. These descriptors were given a simple adjustment (<5 percent in all cases) to their respective data sets that consisted of the ratio of the sum of the descriptor value for the observations to the sum of the actual values.

Eggs.—Within any year of the infestation, egg densit increased with diameter. This positive relation was weakly displayed in years 3 to 6 and more strongly displayed in years 7 to 12 (fig. 1A). This was the net result of more attacks and related increased oviposition in the

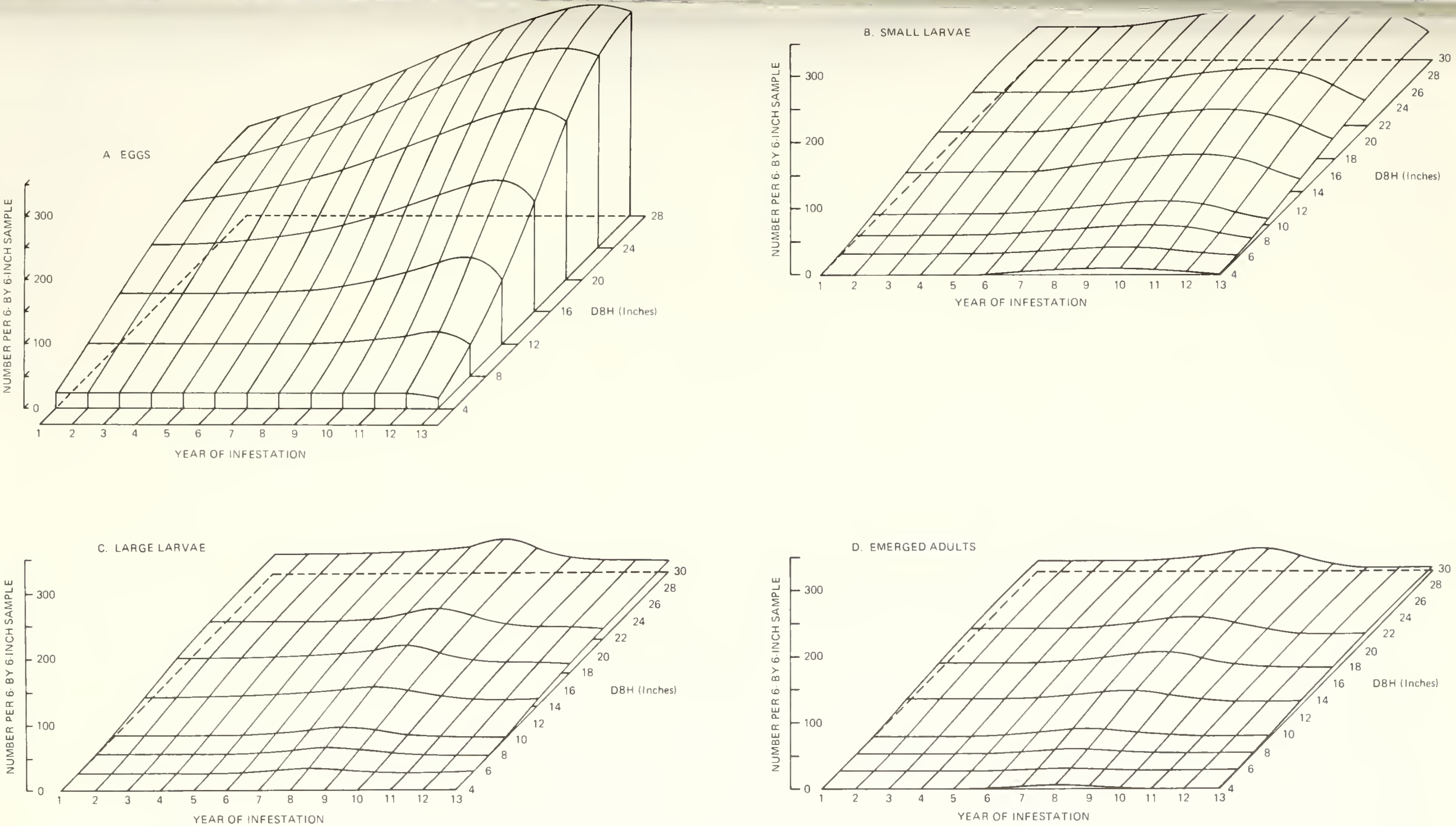


Figure 1.—Densities of four life stages of the mountain pine beetle by tree diameter for 13 years. A. Eggs; B. small larvae; C. large larvae; D. emerged adults (Cole and others 1976).

larger thick-phloem trees early in the epidemic. Of particular interest was the increase in egg density beyond the peak year of emergence (year 8). Apparently, the population and attack density remains high past the peak of the epidemic. Egg density declined slightly in year 13, about 3 years after emergence had returned to the endemic level. Beetles attack fewer trees but at a greater density (Klein and others 1978) following the peak of the epidemic.

Small larvae.—Survival of small larvae through the winter (fig. 1B) also increased with diameter and peaked in the 10th year, 2 years before peak egg deposition. This positive d.b.h. effect existed in all but year 12, and in about half of those years the effect was weak. The negative effect in year 12 was strong. However, the bulk of evidence indicated a positive d.b.h. effect, and this was imposed on year 12, also. The decline in survival that starts with the 11th year probably is related to intraspecific larval competition (within broods) that continues to intensify as egg gallery starts and inches increase with years (fig. 2).

Large larvae.—Survival in the large larval stage (fig. 1C) peaked in year 8, which was 2 years before the peak of small larvae. Large larval survival was relatively steady from year to year within all diameter classes during the endemic period (years 1 to 5). However, survival increased substantially in years 6 to 8.

Low density of large larvae occurs during the endemic years, the result of low levels of attack and gallery density; hence, low density of eggs laid per unit of bark (fig. 1A). Laboratory studies demonstrated that beetle emergence is directly related to inches of egg gallery when phloem is underutilized (fig. 3; Amman 1972). As the infestation progresses and egg galleries increase, an apparent optimum is reached when maximum numbers of large larvae per unit of phloem occur (year 8). After year 8, increased competition among larvae (between galleries), but particularly increased drying, probably causes reduced survival. Increases in attack density and egg gallery density do not cause a decline in beetle surviva per unit area for any given phloem thickness in the laboratory when material remains moist throughout be tle development (Amman and Pace 1976). However, in the field, construction of egg galleries promotes drying of the phloem, especially when gallery density is high. Drying also is enhanced by large numbers of feeding la vae as they exhaust the available phloem.

Adults.—Adult density trends are similar to those of large larvae, but at a reduced level, with the peak still occurring in year 8 (fig. 1D). When development reache the large larval stage, a high probability exists that lar vae will also reach the adult stage. Final emergence wa highly correlated with numbers of individuals in the large larval stage. Emergence within a diameter class was fairly steady during the endemic period (years 1 to 5) but was greater in large diameter trees.

The transition of the infestation from endemic to epidemic is dependent upon successful infestation of large trees, where beetle production per parent is high (fig. 4) Toward the latter years of the epidemic (years 11 to 13) only large trees, on the average, could be expected to produce enough brood to keep the infestation going. However, by this time, few such trees remain in a stand

Mortality factors acting on mountain pine beetle popu lations have been evaluated (Cole 1974, 1981). However, none of these appear to regulate the beetle population a a level that saves trees. An epidemic runs its course, killing most of the large diameter trees, then declines when beetles have only small diameter trees to infest. Beetles must either emigrate from the stand (Klein and others 1978) or infest the small remaining trees in which brood production is low because of thin phloem and excessive drying during beetle development. Therefore, the strong expectation for a positive d.b.h. effect appears correct when considering tree mortality and brood density. These have been reasonably well established by both laboratory and field work.

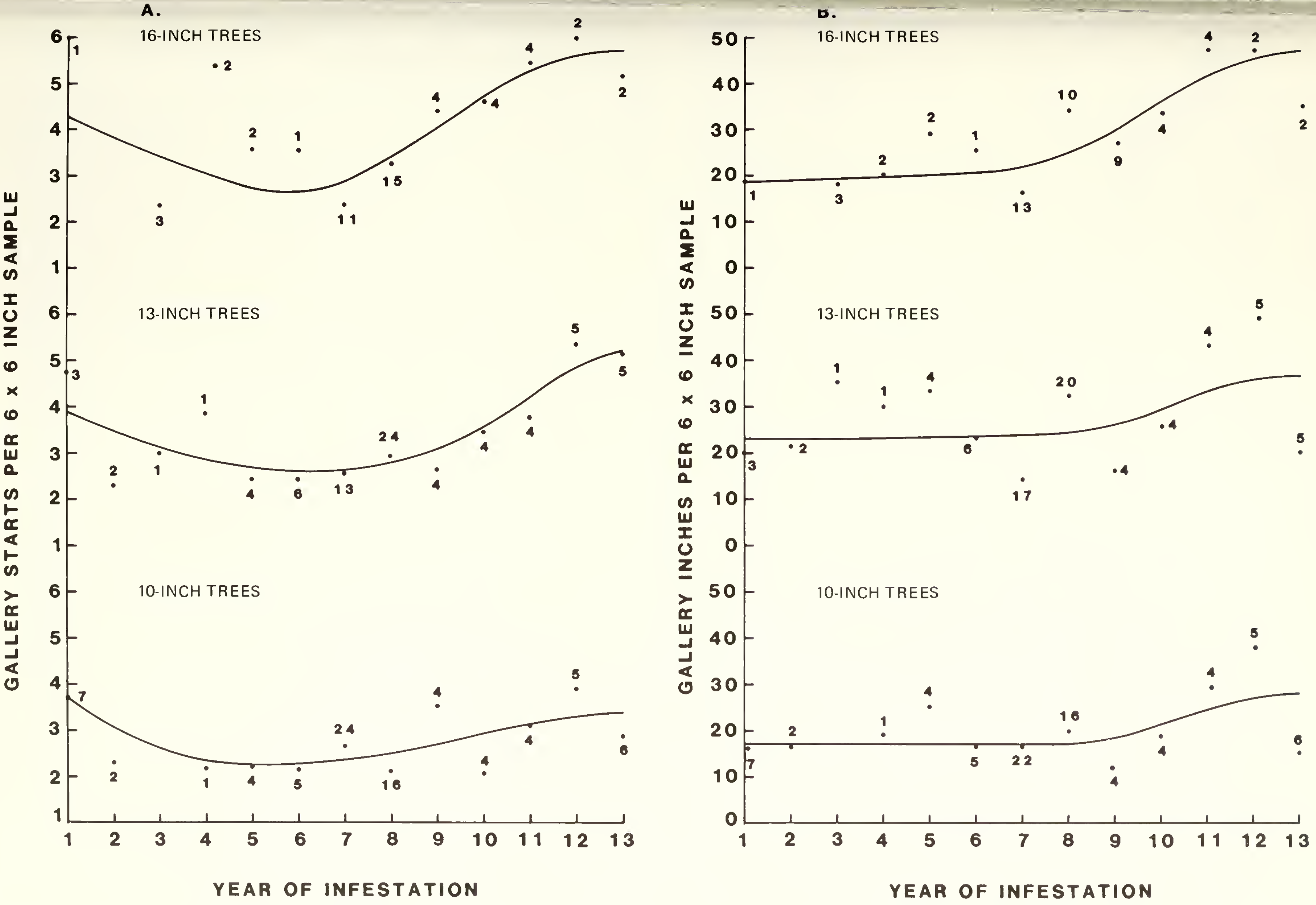


Figure 2.—Mountain pine beetle egg gallery starts and length of egg gallery by diameter for 13 years. A. Egg gallery starts; B. egg gallery inches. Number at each data point indicates number of trees sampled (Cole and others 1976).

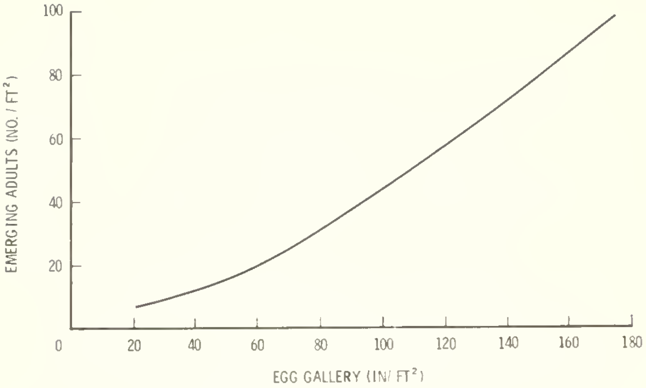


Figure 3.—Relation between number of emerging brood adults of the mountain pine beetle and inches of egg gallery made by parent adults in thick phloem (0.16 to 0.26 inch or 4.1 to 6.6 mm thick; $\hat{y} = 3.26 + 0.0408\,(x^{1.5})$; $s_{y \cdot x} = 24$; $r^2 = 0.52$) (Amman 1972).

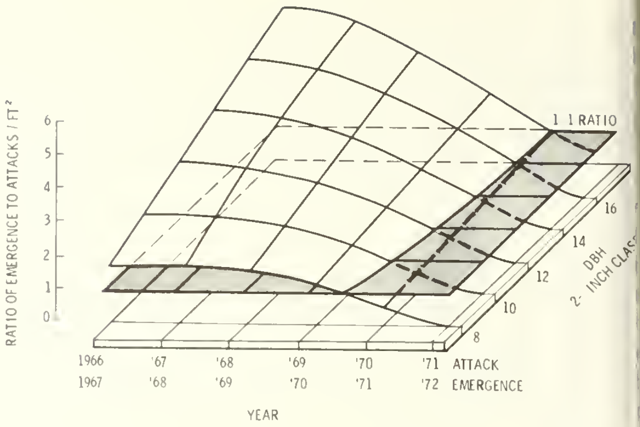


Figure 4.—Ratio of emergence to attack densities by 2-inch (5.1-cm) diameter classes during a mountain pine beetle epidemic (Klein and others 1978).

Beetle Dispersion and Aggregation Models

Upon completion of development, most of the new mountain pine beetle adults emerge in late July and early August. They disperse and, when a green tree is attacked by one or a few beetles, the aggregation pheromone is released that attracts many beetles for a mass attack of the tree.

Dispersion/aggregation model.—Burnell (1977) devised an elegant model that disperses the beetles based on a random distribution that, one could argue, is a rarity in nature. He used three assumptions in dispersal/aggregation:

1. Pioneer beetles attack with random distribution over the available bark surface.
2. A tree has a threshold of aggregation that is required to induce aggregation.
3. Any tree becoming an aggregator will be mass attacked and killed.

He assumed the tree surface areas are measured in equivalent units. Then the pioneer beetle attack density per unit could be estimated using the Poisson distribution function, and the probability of having one or more pioneer beetles attack could be calculated. The threshold of aggregation was estimated based on the number of square units of the tree that must be attacked by one or more pioneer beetles to induce aggregation. Thus, the probability of the tree becoming an aggregator could be calculated.

The mortality prediction model assumed that the threshold of aggregation is uniform across both diameter and years within an epidemic. Thus, surface killed was estimated for the stand. However, for each year, the predicted surface area mortality was forced to be the same as that observed by adjusting the pioneer beetle attack density. Therefore, using Burnell's (1977) equation to determine the threshold of aggregation minimizes the difference between predicted and residual stands.

Burnell determined the thresholds of aggregation for four plots. One plot, Hell Roaring Creek, with a rather high threshold of aggregation but also high attack densities and host resinosis, was interpreted as being more resistant to attack than the other stands. Burnell interpreted this as a stand resistance measure. Howeve subsequent years of infestation proved this incorrect as large numbers of trees were killed.

Burnell's model shows that in the early part of the epidemic the pioneer density is low and the comparative probability of large tree mortality versus small tree mortality is large. As the epidemic progresses, pioneer density rises and smaller trees are attacked because of this and the depletion of larger trees. Toward the end of the epidemic, pioneer beetle density decreases because emergence from infested trees declines and, as a result, the epidemic collapses. However, data taken from many epidemics (Cole and others 1976) show that gallery starts (the positive results of attack densities) are greater in the early stages of an epidemic (fig. 2), decreasing in the midyears, and increasing again in the latter years.

Aggregation/susceptibility model.—Geiszler and other (1980) developed a mathematical model to (1) describe beetle aggregation and (2) predict the relation of tree susceptibility and switching to changes in beetle density The term "switching" is defined as the phenomenon of incoming beetles attacking an adjacent recipient tree after the focus (first) tree had been attacked by the first arriving beetle. This receipient tree is quickly mass-attacked and killed more readily than the focus tree. These authors found that, when switching occurs, the beetles usually attack trees with a diameter greater tha the average in the stand. This then enhances beetle survival because larger trees usually have thick phloem. There are at least three other conceptual models describing the switching process of attacking bark beetles. Geiszler and others (1980) labeled them as:

1. Passive model when the signal to switch is due to lack of resin exudation (Renwick and Vité 1970).

2. Threshold model when the attractive pheromone, **rans**-verbenol, is assumed to be the cause of switching oster and Gara 1968).

3. Repelling model when both **trans**-verbenol and a epelling pheromone reach concentrations that cause witching (Rudinsky and others 1974).

In developing the Geiszler and others model to decribe daily number of beetle attacks on the lower 7.9 ft .4 m) of a single tree, primary factors assumed to conrol the attack pattern were attraction, repellence, and ost factors that affect successful beetle colonization. ttraction was assumed to depend primarily upon the mount of attractant released, the population density of lying beetles, and meteorological conditions. Attraction as then modeled, based upon the amount and emission ate of **trans**-verbenol for 2 days. Repellence was odeled on the assumption that the repellent concentraion increased linearly with the cumulative number of ttacks. Resistance, by the tree, to aggregation was odeled by determining the number of unsuccessful ttacks each day of the study. Thus, the main factors of ggregation were accounted for and the temporal pattern f attack was modeled. This model was then used to imulate the daily and cumulative number of attacks on he focus tree.

The attraction coefficient values varied, suggesting hat (1) each tree's attractive qualities were different, (2) he local beetle population density at each tree's site was ifferent and compensated for by adjusting the attracant and coefficient, or (3) both. Repellence also varied nd was positively correlated with total number of ttacks and tree diameters. Inclusion of tree resistance nto the model had little or no effect on the predictions, ue to a rapid attack rate at population levels during his study.

Geiszler and others concluded from their model that, if he total attacks on a tree are limited by a repelling echanism at high population densities, and the number f repelled beetles is large, these repelled beetles switch" from the focus tree to attack adjacent trees in verwhelming numbers. They also considered switching ttacks a critical factor contributing to outbreaks. Furher, if switching can be disrupted (for instance, by thinning stands), the repelled beetles will disperse, numbers vill be reduced, and fewer attacks will occur in a new rea. Most previous studies have been concerned with ost attraction, physiological responses, stand factors, limate, age, and other factors. This study was one of he few (if not the only study) to consider population ensity of the flying beetles. Failing to include populaion density in these other studies, particularly the tree susceptibility/resistance studies, may be the reason so many inconsistencies resulted. The results from this modeling of aggregation clearly indicate that population density is important to colonization of the tree, the number of beetles repelled, and subsequent switching from the focus tree. The results were verified, correspondingly, to field observations.

Stand-Beetle Models

Interactions of the beetle with the infested trees, and tree losses to the beetles within stands, follow a predictable pattern. The green stand in which a beetle epidemic might be expected—trees 4 inches (10.2 cm) d.b.h. and larger—contains a relatively large proportion of trees over 12 inches (30.5 cm) in diameter (22 percent in the case described here, fig. 5). A large proportion of trees 12 inches d.b.h. and larger provides the threshold food supply necessary for an epidemic because of the thick phloem found in such trees (Cole and Cahill 1976). The epidemic potential exists primarily under optimal temperatures for beetle development (Amman and Baker 1972; Amman 1973; Safranyik and others 1974).

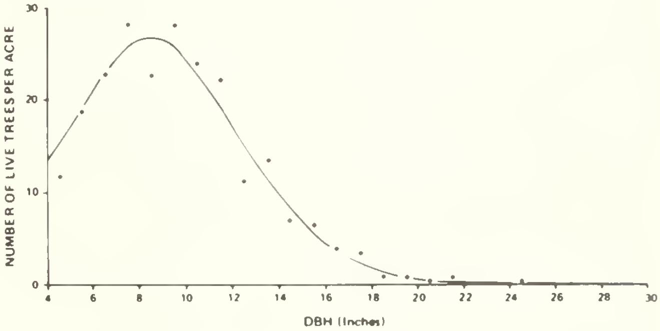


Figure 5.—Green stand structure of lodgepole pine at the beginning of the mountain pine beetle infestation (Cole and others 1976).

Losses of lodgepole pine over the main epidemic years are proportionately much greater in the large diameter classes (fig. 6A). Most tree losses occurred during a 6-year period. Cumulative losses show that most large diameter trees were killed during the infestation (fig. 6B). Losses ranged from about 84 percent of the large trees to about 40 percent of the small trees. Losses shown are typical for stands of trees of similar size and distribution at similar elevations and latitudes in northwestern Wyoming and southeastern Idaho (Amman and Baker 1972).

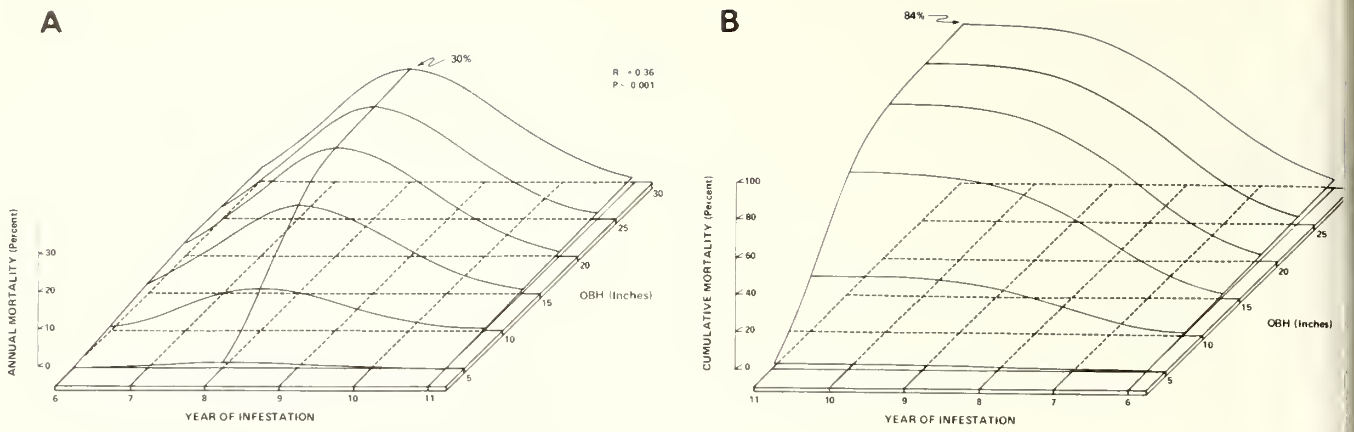


Figure 6.—Losses of lodgepole pine by diameter class and year during an infestation of the mountain pine beetle. A. Annual mortality percent of original stand ($r^2 = 0.36$; $P < 0.001$); B. cumulative mortality percent.

Stand-beetle interaction models.—Stand models and beetle models were incorporated for selected years spanning the infestation to show interactions. When comparing the green stand and tree mortality models with the beetle brood models for the main epidemic years, the following years essentially correspond: residual stand or annual mortality model year 1 = beetle model years 1 through 5; 2 = 6; 3 = 7; 4 = 8 (peak year); 5 = 9; 6 = 10; and 7 = 11 through 13. Figure 7A represents a year when the beetle population was endemic. Curves by beetle stages show expected survival in a tree of any specific diameter, if it becomes infested.

During year 8, both emergence and tree losses peaked (fig. 7B). Compared to year 1, both egg density and adult emergence approximately doubled. The fact that gallery inches and egg densities continue to rise in following years, but emergence declines, indicates that gallery density and subsequent larval population reached an optimum in year 8. Cumulative tree mortality is substantial, with about half the trees killed by year 8. Numerically, losses appear similar for the different diameter classes. Proportionately, however, losses are much greater for the large diameter classes.

Year 10 (fig. 7C) shows a large increase in eggs, but the number of small larvae surviving through the winte was about the same as in year 8, and the number of su viving large larvae was much reduced. Emergence now approximates the level that occurred during the endemi period (fig. 7A), but tree losses do not. Cumulative tree losses (50 percent) in year 8 have increased to 83 percent by year 10 (fig. 7C), primarily because of high eme gence and correspondingly high tree losses during year 9.

In year 12 (fig. 7D), the high egg densities resulted i high larval mortality, probably from severe competition for food and drying of phloem. Subsequent emergence, accordance with expectations, was even lower than in preepidemic years (1 through 5). Emergence should return to these levels when egg gallery densities return t their original endemic levels (year 1). By year 12, cumulative tree mortality had leveled off and annual tree mortality had returned to the endemic level. Cumulativ losses in the stand do not appear overwhelming (fig. 7D However, most of the trees that were over 12 inches (30.5 cm) d.b.h. had been killed. Mortality ranged from 42 percent of the 12-inch trees to 84 percent for trees 3 inches (76.2 cm) and over.

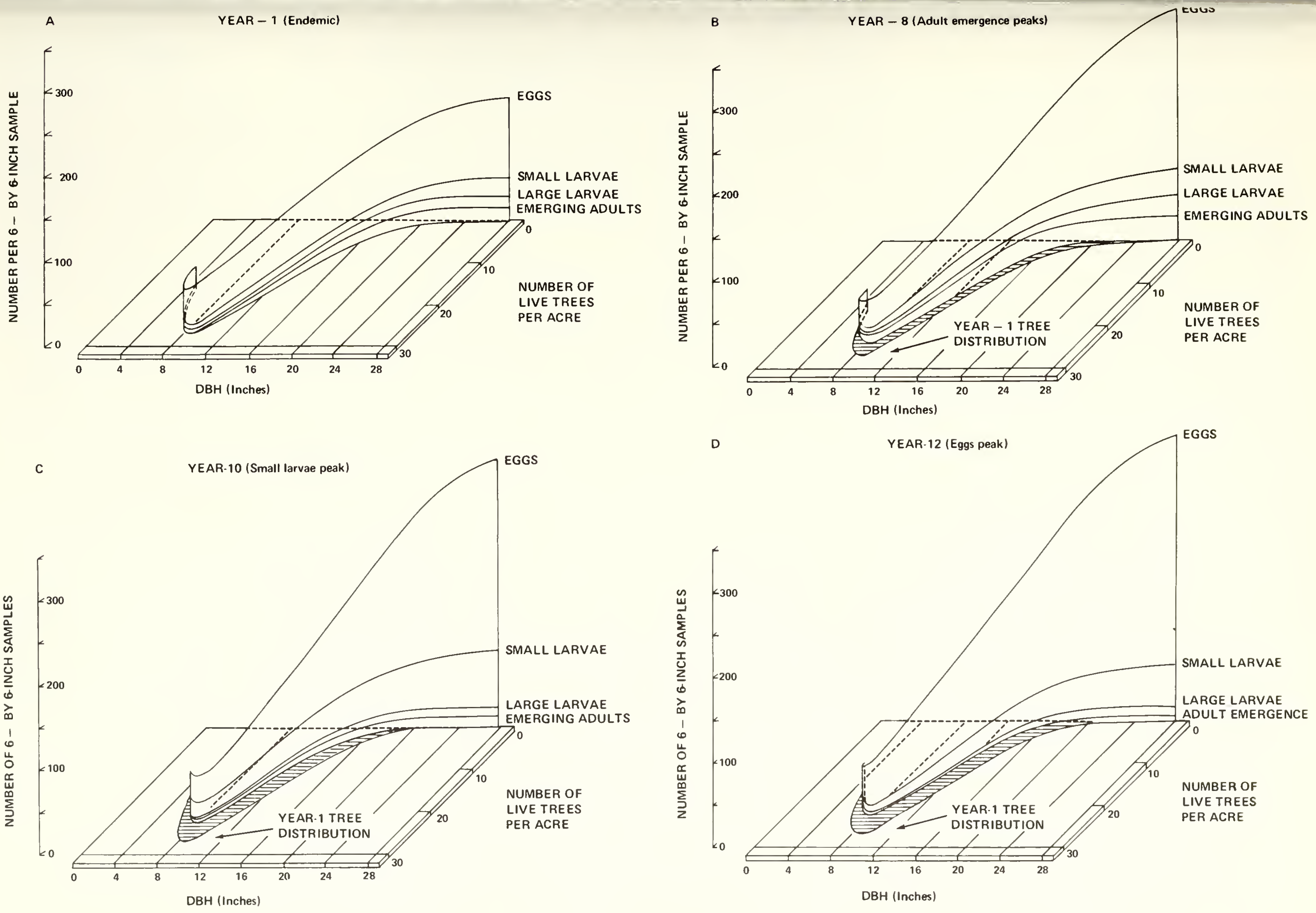


Figure 7.—Interaction models of beetle survival and lodgepole pine losses. A. Year 1 (endemic beetle population level); B. year 8 (peak adult emergence); C. year 10 (peak small larval density); D. year 12 (peak egg density) (Cole and others 1976).

In the interaction models (Cole and others 1976), the close association of beetle dynamics with numbers and sizes of trees that are infested can be seen at any point in the epidemic. For example, emergence diminishes rapidly as the large trees are killed. Beetles then tend to infest a higher proportion of smaller trees. Coincident with this are increased numbers of gallery starts, gallery inches, and subsequent egg densities. These continue to rise through year 12, even though emergence has declined drastically. Brood in small trees having thin phloem tend on the average to have higher proportions of females than are found in large trees having thick phloem (fig. 8), because females survive better under stress than males. W. E. Cole (1973) demonstrated that females survived in greater proportion than males when crowding of larvae increased, and Amman and Rasmussen (1974) found that female survival was greater than that of males when drying of bark increased.

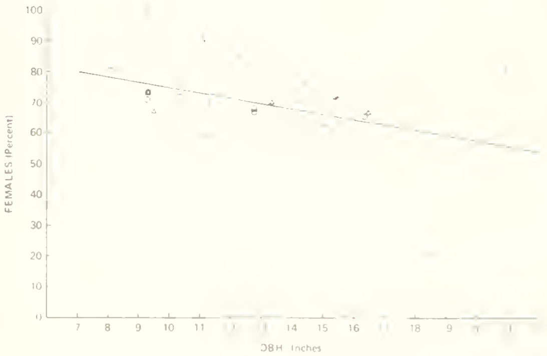


Figure 8.—Proportion of female mountain pine beetles per tree in the emerging population from infested lodgepole pine on the Wasatch National Forest, 1972 to 1974. $\hat{Y} = 91.8 - 1.68x$; $s_{y \cdot x} = 13.1$; $r^2 = 0.13$; $P<0.025$ (Cole and others 1976).

The increase in density of gallery starts and subsequent gallery inches may be related to a changing sex ratio in the beetle population (fig. 9) (Amman and Cole 1983), as related to the beetles' aggregative and antiaggregative pheromone system. Starting about the time of peak emergence (year 8), it appears that insufficient males exist to mate most females in a relatively short time. Hence, unmated females continue to produce the aggregative pheromone, trans-verbenol, which attracts additional females. Male and mated female mountain pine beetles produce an antiaggregative pheromone that stops additional attacks on the tree (Rudinsky and others 1974).

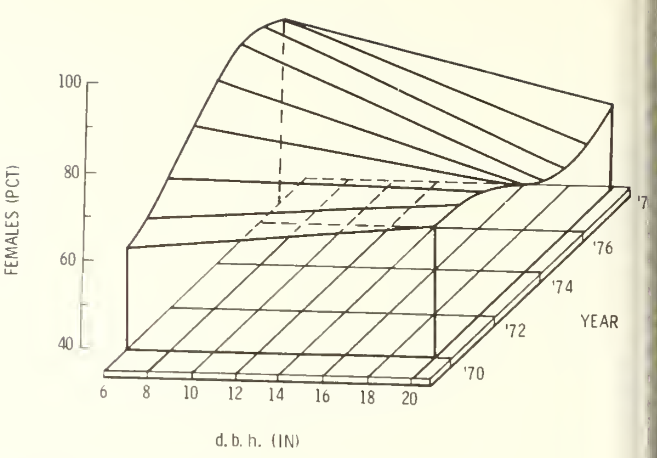


Figure 9.—Sex ratios of mountain pine beetle populations differ by diameter of lodgepole pine and year of infestation, Wasatch-Cache National Forest, UT.

A synoptic model showing the overall beetle-stand dynamics is presented in figure 10. Survival of females is greater than males within small diameter trees that are infested during early stages of stand development. Attack densities of beetles are high at this time, although limited to the base of the tree, and are related to the low proportion of males in the population. Males, either upon reaching a tree under attack or upon mating, along with mated females, release a chemical messenger (pheromone) that signals arriving females that the tree is occupied, thus countering the aggregative pheromone of the unmated female beetle (Rudinsky 1968). With few males present, the buildup of the antiaggregative pheromone is slow. This results in a high attack density, thereby limiting brood production to some extent. However, on the positive side for such a behavioral mechanism is that sufficient population is usually attracted to kill a tree, thus assuring some brood production.

As the stand grows into pole sizes, with some trees exceeding 16 inches (41 cm) d.b.h., more food in the form of phloem is available; and the sapwood of the large trees is thick so that excessive drying does not occur during beetle brood production. Beetle production is usually low in the widely scattered, small diameter trees infested during the endemic population phase. When several of these infested trees are in close enough proximity that emerging brood key on and infest a common tree of large diameter with thick phloem, brood production is greatly increased. In such trees, production of males and females becomes more even. A more even sex ratio has been associated with reduced attack density because adequate numbers of males are present to rapidly mate all females, resulting in a high concentration of antiaggregative pheromone that stops additional

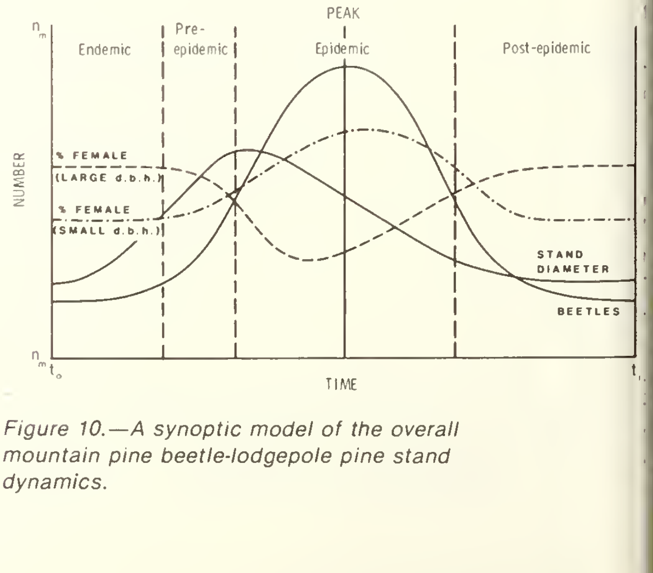


Figure 10.—A synoptic model of the overall mountain pine beetle-lodgepole pine stand dynamics.

male attacks. The result is increased beetle production, llowed by a rapid increase in infested trees as the bee-e population disperses more efficiently over attacked ees.

When most of the large diameter trees (which usually ave thick phloem) are killed, the beetles infest progres-vely smaller diameter trees (Cole and Amman 1969; lein and others 1978). Conditions in these trees are milar to those in trees attacked early in the infestation ycle—thin phloem and excessive drying. Brood produc-on is low and sex ratio shifts back toward females in ich trees. After the initial infestation in a stand, which ay require 60 to 80 years, successive outbreaks can be xpected in 20- to 40-year intervals (Roe and Amman 970). Residual trees are 4 to 10 inches (10.2 to 25.4 cm) .b.h., with a few trees greater than 10 inches missed by ne beetle. Because of the thinning of the stand by the eetles, additional growing space is provided and, within few years, substantial ingrowth occurs (Klein 1978). Vithin the 20- to 40-year period, enough large diameter rees with thick phloem are available for another beetle utbreak to occur. In this conceptual model, beetle dy-amics are tied to tree and stand dynamics. Stress of rees or stands is not necessary for beetles to become pidemic. As beetle numbers build up, they are able to nfest and kill any of the trees.

Tree and stand stress as a factor.—The Cole, Amman, ensen efforts have avoided tree and stand stress factors s important in the dynamics of mountain pine beetle in odgepole pine. They use tree diameter as the important lement for outbreaks to occur. Larger trees have thick hloem, which is associated with characteristics of good ree vigor (D. M. Cole 1973).

However, Berryman (1976) and Safranyik and others 1975) introduce the element of tree and stand stress as ssential for outbreaks to occur. Stress is deemed necessary because large diameter trees with thick phloem are the most vigorous in the stands (D.M. Cole 1973; Shrimpton 1973; Roe and Amman 1970). Stress is considered needed in order for beetles to overcome the trees' resinous defenses. The higher attack densities on large diameter rather than on small diameter trees (Cole and others 1976; Klein and others 1978) are a direct response of the beetles to vigor of these trees. The Berryman (1976) model consists of three variables—phloem thickness, tree resistance, and assumed replacement productivity level for the mountain pine bettle. Stand or tree resistance is measured by periodic growth ratios (PGR),

$$\text{PGR} = \frac{\text{current 5 years radial growth}}{\text{previous 5 years radial growth}}$$

(Mahoney 1978), or a stand hazard rating (SHR), SHR = CCF × %LPPBA (lodgepole pine basal area)(Schenk and others 1980). For a discussion of CCF (crown competition factor) see Krajicek and others (1961). The theoretical model shows that, as phloem thickness increases and stand resistance declines, beetle production increases, thus increasing the chances for a beetle outbreak. Stands that contain less than 10 percent of basal area in trees with phloem ≥ 0.1 inch (2.5 mm) thick have little or no chance of mountain pine beetle outbreak (Berryman 1978).

Another idea recently introduced as a way to determine susceptibility of trees and stands to mountain pine beetle infestation is growth efficiency (Waring and Pitman 1980). Only those trees with low growth efficiency are believed to be susceptible to successful infestation by mountain pine beetle. The established relation between conifer foliage mass and sapwood area makes growth efficiency relatively easy to measure (Grier and Waring 1974).

A test of SHR and PGR (McGregor 1978; McGregor and others 1981) showed that mortality is inversely, rather than directly, related to SHR, and that mortality is directly related to PGR rather than inversely, as required by the theoretical model (Berryman 1976). McGregor and others (1981), in an examination of 62 lodgepole pine stands in Montana, demonstrated that percentage lodgepole pine mortality increased with reduced CCF (fig. 11). Stands examined were 100 percent or nearly 100 percent lodgepole pine; therefore, SHR = CCF. Using the growth efficiency method (Waring and Pitman 1980), four of five stands measured on the Targhee National Forest showed no difference between grams of wood per square meter of foliage for surviving and killed trees ($P > 0.05$) (table 16). A significant difference was shown in the fifth stand ($P < 0.001$); infested trees showed lower growth efficiency than residual green trees. However, dominant and codominant green trees were compared with all trees killed by mountain pine beetle regardless of crown class, in all stands and were much younger. Therefore, the data are biased toward green trees. Using the Berryman model (1978) all five stands were classed low in susceptibility even though three of them had 22 to 30 percent of the lodgepole killed by beetles.

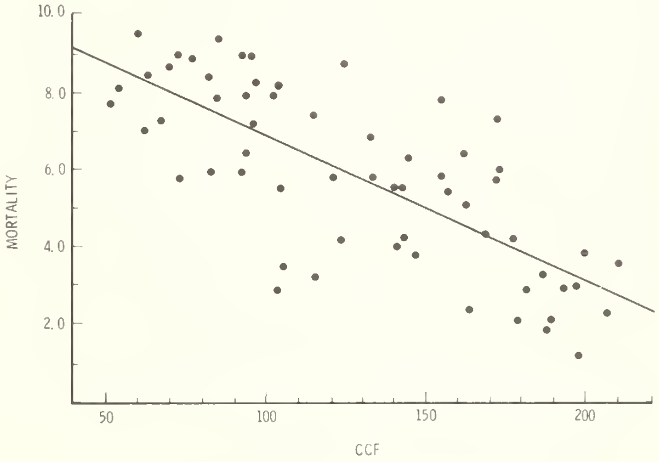


Figure 11.—Losses of lodgepole pine are inversely related to CCF for 62 stands in Montana, 1978 to 1979. Note: Data transformed, $Y' = \sqrt{Y + 3/8}$; $r^2 = 0.57$; $P<0.01$.

It could be argued that, once populations build up, the relation between the beetle and vigor of the tree changes. Whether a tree can be successfully infested is a function of attack density; that is, the number of available beetles. In other words, when beetles are plentiful, any tree can be infested successfully. At low population

Table 16.—Comparisons of lodgepole pine growth efficiency (Waring – Pitman method) and periodic growth ratios (Mahoney method) between surviving trees and trees killed by mountain pine beetles, Targhee National Forest, ID, 1980

Plot	Grams of wood per m^2 foliage[1]			Periodic growth rate[2]		
	Green trees	Infested trees	t-test	Green trees	Infested trees	t-test
Horseshoe-Packsaddle	56.4	58.9	$P > 0.500$ NS	0.884	0.873	$P > 0.100$ NS
Pine Creek	67.0	60.0	$P > .400$ NS	.939	1.018	$P < .001$ S
Indian Lake	91.2	75.3	$P > .050$ NS	1.271	1.303	$P > .100$ NS
Moody Meadows	76.0	97.4	$P > .200$ NS	1.067	1.080	$P > .500$ NS
Warm River	120.9	63.6	$P < .001$ S	.879	.917	$P < .020$ S

[1] Susceptibility to beetle infestation:
High = 10-50
Moderate = 51-100
Low = > 100.

[2] Susceptible to attack = < 0.90.
Resistant to attack = > 0.90.

levels difficulty in making a successful attack could be expected. In the Moody Meadows stand on the Targhee National Forest, the fewest infested trees occurred—four infested trees over 4 years = 0.53 tree per acre (1.31/ha) per year. Even at this low infestation rate, PGR's of infested trees ranged between 0.88 and 1.27 ($\bar{x} = 1.08$). Diameters ranged between 10 and 19 inches d.b.h. (25 to 48 cm), with the 19-inch tree having a PGR of 1.21. Grams of wood per square meter of foliage averaged 97.4 (range 67 to 113). Two of the three trees (sapwood was not measured on the fourth tree) exceeded 100 g/m^2. Trees exceeding that rate have low susceptibility to beetle infestation (G. B. Pitman, letter dated March 25, 1982). If CCF, PGR, and grams of wood per square meter of foliage are indeed good measures of tree and stand vigor, then the relation of mountain pine outbreaks to these variables appears to be reversed. Infestations tend to increase rather than decline with these measures of tree and stand vigor.

Stand growth stress and beetle model.—Stress as a factor in a stand growth-beetle model was introduced by Crookston and others (1978). Stand stress, based on PGR (Mahoney 1978), is used as a mechanism of triggering an epidemic. The mountain pine beetle portion is comprised of two major components. The first is a flight and attack model that includes submodels of emergence, distribution, flight mortality, and effect of beetle-aggregating pheromones. Trees that are attacked and killed are based on the dispersal-aggregation model of Burnell (1977).

This beetle model has been added, as an extension, to the stand growth prognosis model for stand development (Stage 1973). The linkage is presented by Crookston and others (1978). There are three main components:

1. The decision algorithm that controls when the outbreak will occur.
2. The data transmission algorithm that derives required stand parameters.
3. The damage algorithm that reduces the tree population.

The conceptual program flow is shown in figure 12. The probability of an outbreak occurring is based on crown competition factor and the proportion of basal area in lodgepole pine (Schenk and others 1980). However, the relation of CCF and susceptiblity to mountain pine beetle infestation may be valid only for a small part of the lodgepole pine type (Amman in press).

Output of the model is expected stand development from time of inventory until specified rotation. When a beetle epidemic is simulated, information about expected dynamic beetle-tree interactions is generated, including numbers of live and dead trees by d.b.h. class and year of infestation. Algorithms used in these models can be obtained from Crookston and others (1978).

Rate of Tree Loss Model

The rate of loss model refines existing risk-rating systems and provides a method for stratifying lodgepole pine stands and predicting tree and volume loss for habitat types (Cole and McGregor 1983). The model is provided to assist land managers in projecting tree mortality over time, and can be linked to the FORPLAN (Johnson and others 1980) model for use in forest planning.

Most models for epidemic processes have dealt with the continuous-infection model for treating epidemic processes in a fully stochastic manner (that is, probabilistic), and most of these processes dealt with diseases. Consequently, derivatives of the word "infect" rather than "infest" are used. Continuous infection assumes that an individual (the host tree) can be infectious from the moment it receives the infection (the beetle) until it dies, recovers, or is removed. This clearly is not the case with the mountain pine beetle. The mountain pine beetle has a discrete generation and discrete stages of growth, and its epidemic behavior does not fit the continuous-infection assumptions.

An alternative to the continuous-infection assumption was established by Reed and Frost in 1928 (Abbey 1952) and by Greenwood (1931). They postulated that the period of infectiousness is comparatively short, and the latent and incubation periods are constant (Bailey 1957). This alternative assumption best fits the epidemic behavior of the mountain pine beetle and amount of tree

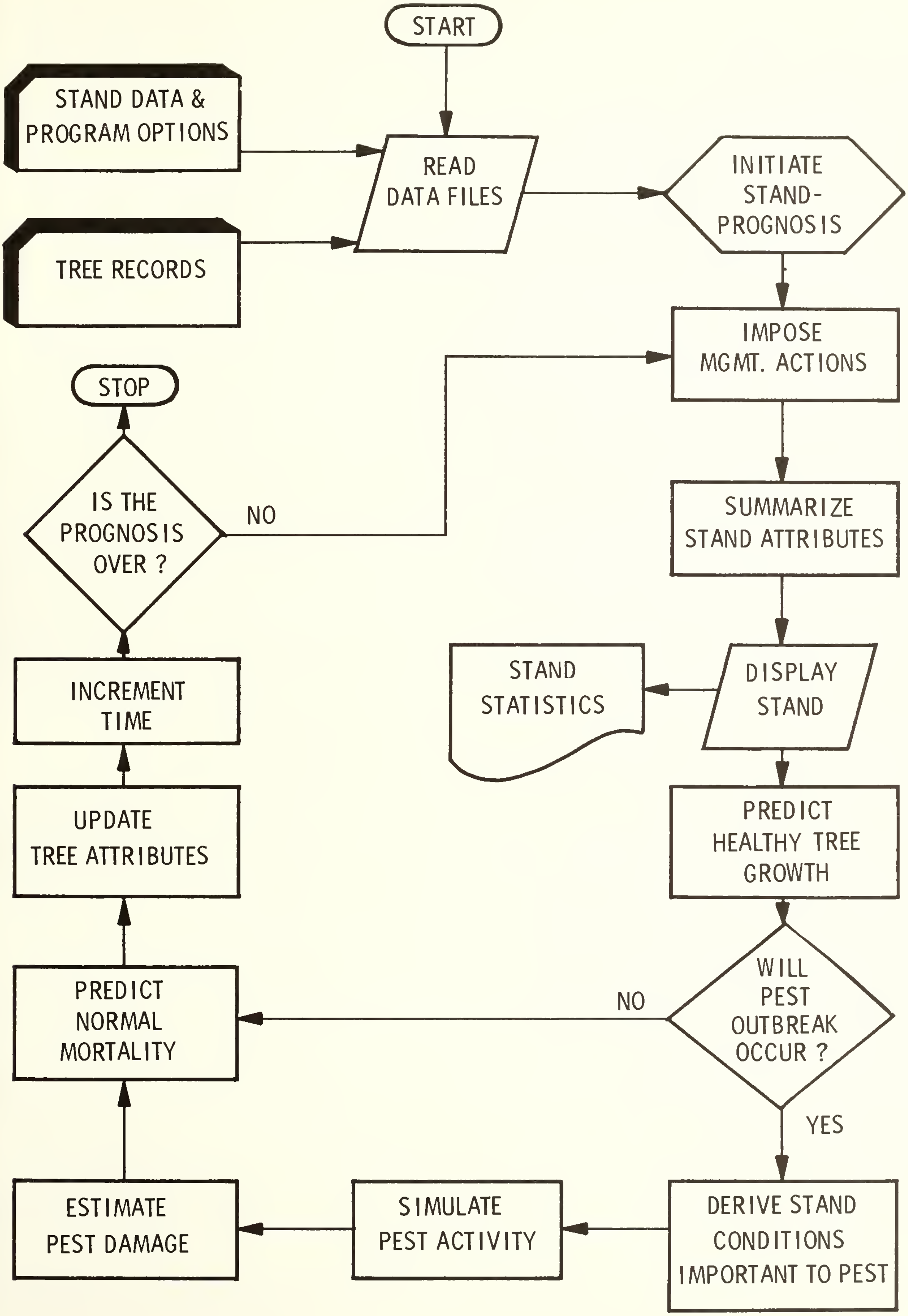


Figure 12.—Conceptual program flow of the stand prognosis model with an optionally linked pest simulation submodel (Crookston 1978).

loss. In lodgepole pine stands in the Intermountain West, the period of infecting a tree (beetle attack) is fairly short (approximately 1 day for one tree and up to 4 to 6 weeks within a stand). The latent period is the time development of the infective that takes place without the emission of any infectious material (brood development). And the incubation period is the elapsed time between the receipt of the infection and the appearance of symptoms (time between attack and foliage discoloration). Both the latent and incubation periods can be considered constant in relation to the life cycle of the beetle and fading of tree foliage.

A first approximation model assumes the following: latent and incubation periods are constant, period of infectiousness is reduced to a single point, and a single attack confers immunity. At each stage in the epidemic, there are certain numbers of infectives and susceptibles, and it is reasonable to suppose that the latter will yield a fresh crop of cases at the next stage, distributed in a binomial series. This results in a chain of binomial distributions, with actual probability of a new infection at any stage being dependent on the numbers of infectives and susceptibles in the previous stage.

Three restrictions of the chain binomial model exist that would invalidate the model: (1) substantial departures from the assumptions of constant incubation and latent periods, (2) a very short infectious period, and (3) failure to properly identify the links of the chain. However, an alternative exists when a highly variable incubation period occurs or the symptoms cannot be identified correctly. In such cases, the analysis can be based on the total number of cases occurring during the course of the epidemic. However, some loss of precision results with estimations. When numbers infected are large, frequencies of infection can be calculated directly and will probably be more accurate than those derived from the probabilities of the individual chains.

Concerning the assumptions of short infectiousness and constant incubation and latent periods, a beetle outbreak can begin with one or several simultaneously infested trees within a stand. The infestation then will spread in a series of stages by each new generation of adult beetles attacking living green trees. If the stand of trees is suitable for successful brood production by the beetles, we expect the number of trees killed at any stage to have a binomial distribution based upon numbers of susceptible and infested trees. Therefore, we have a chain of binomial distributions throughout the course of a mountain pine beetle epidemic. The probability of a tree becoming infested at any generation depends upon the numbers of infested trees and susceptible green trees during the preceding generation of beetles.

Therefore, an epidemic started by beetles from a single infested tree, or by several trees infested simultaneously, will continue in a series of stages (generations of beetles) until either no more beetles are left to attack green trees or no more green trees are left to be attacked. There will be a certain number of infested trees and a certain number of susceptibles in each stage (each beetle generation) of an epidemic. These remaining susceptibles can be attacked by a new generation of beetles, and the newly infested trees will be distributed in a binomial series. Thus, a chain of binomial distributions occurs. The assumptions underlying models based on discrete time usually consider all susceptible and infested individuals to be mixed homogeneously. This situation, more nearly represented by small groups of trees, does not hold with large stands. However, incubation (time interval between the infesting of a tree or stand and the appearance of symptoms) and latent periods (interval in which insect development takes place within the tree) are not variable. Therefore, infesting of a tree is considered a relatively short period. As this model was refined, factors were included that govern tree and stand susceptibility, as well as factors that affect the life processes of beetle population including habitat type, elevation, diameter distribution in a stand, and phloem thickness distribution.

Model description.—If p is the probability of a tree becoming infested in a given time, then $q = 1 - p$ is the probability of a tree not becoming infested. The probability of a tree becoming infested, in this sense, depends on the susceptibility or resistance of the tree, the infestivity of the beetle, the length of attack period, and the size of the attacking beetle population, as well as the environmental conditions of the stand.

If D_t is the number of trees infested at time t, then q^{D_t} is the probability that the specified tree will not be infested, and $1 - q^{D_t}$ is the probability that the tree will be infested. It follows that if there are G_t green trees capable of being infested in the population at time t, the expected number of infested trees produced at the time t+1 is G_t times the probability of at least one tree being infested. Or,

$$D_{t+1} = G_t (1 - q^{D_t}) \text{ and } G_{t+1} = G_t q^{D_t}$$

This equation provides a method of stepwise calculation of trees infested at successive periods. Calculations for a theoretical beetle epidemic are presented in table 17. If $G_t = 0$, all the trees are dead and the epidemic subsides due to food depletion. If $D_t = 0$, beetles are no longer reproducing successfully and the epidemic subsides.

The Greenwood model postulates that the probability of a susceptible tree being infested is a constant and is not related to the number of infectives. In other words, a susceptible tree in a stand with one infective is as likely to get attacked as the same tree surrounded by many infectives. This is obviously not the case, because trees adjacent to a freshly attacked tree are more likely to be infested than more distant trees (Geiszler and others 1980). Thus, we adopted the Reed-Frost model for susceptibility because it accounts for the increase in infestation pressure due to the number of infested trees. In the Reed-Frost model, the probability of a tree not being infested from only one source is taken to be a constant, q. The probability of not being infested from two sources is thus (q)(q) and, consequently, from n sources it is q^n.

The value of q can be calculated from these relationships by solving the equation of G_{t+1} for q. This yields

$$q = (G_{t+1} / G_t)^{(1/D_t)}$$

able 17.—Calculation of theoretical epidemic of mountain pine beetles from the Reed–Frost model (p = 0.5)

Time period	Number of dead trees (D)	Number of susceptible trees (G)	Calculation of D_{t+1} and G_{t+1}
0	1	100	$D_1 = 100\ (1 - 0.95) = 5.00 = 5$ $G_1 = 100 - 5 = 95$
1	5	95	$D_2 = 95\ (1 - 0.95^5) = 21.49 = 21$ $G_2 = 95 - 21 = 74$
2	21	74	$D_3 = 74\ (1 - 0.95^{21}) = 48.80 = 29$ $G_3 = 74 - 49 = 25$
3	49	25	$D_4 = 25\ (1 - 0.95^{49}) = 22.97 = 23$ $G_4 = 25 - 23 = 2$
4	23	2	$D_5 = 2\ (1 - 0.95^{23}) = 1.39 = 1$ $G_5 = 2 - 1 = 1$
5	1	1	$D_6 = 1\ (1 - 0.95^7) = 0.05 = 0$ $G_6 = 1 - 0 = 1$
6	0	1	

Theoretically, q will be a constant, but the real world s never constant. Thus, the q for time (q_t) varies slightly with t and may be determined for each time interval. However, a closer prediction of D_{t+1} can be obtained when several values for q_t are calculated, and q estimated by q_t for several stands.

Testing the model.—Two sets of published data were used to test the model. The first set came from a mountain pine beetle infestation in the Bechler River Drainage of Yellowstone National Park (Klein and others 1978). These data were grouped into the following categories: (1) by 2-inch (5.1-cm) diameter classes; (2) by 6- to 12-inch (15.2- to 30.5-cm), 14- to 16-inch (35.6- to 40.6-cm), and greater than 16-inch (40.6-cm) d.b.h. classes; and (3) by total stand (tables 18 and 19) (figs. 13 and 14). From these, tree losses were predicted for this stand. A close fit to actual losses was obtained.

Table 18.—Predicted versus observed tree losses to the mountain pine beetle by year based on $\bar{q}_t$, for 2-inch (5.1-cm) tree diameter classes (Situation A, observed data from Klein and others 1978)

		Number of trees per acre				
Diameter class	Year of infestation	Green (G)	Dead (D)	$1/D_t$	q_t[1]	Predicted tree loss
6-inch (15.2-cm)	0	79.8	0.3	3.333	0.9875	0.14
	1	79.5	0	0	1.0000	0
	2	79.5	.3	3.333	.9857	.14
	3	79.2	2.1	.476	.9873	.99
	4	77.1	0	0	1.0000	0
	5	77.1	0	0	1.0000	0
	6	77.1	0	0		0
		Total loss	2.7	Average	0.9937	1.27
			(1.1/ha)			(0.51/ha)
8-inch (20.3-cm)	0	62.7	0.8	1.250	0.984	0.90
	1	61.9	.8	1.250	.984	.89
	2	61.1	2.7	.370	.983	2.92
	3	58.4	8.1	.120	.982	7.99
	4	50.3	.7	1.430	.980	.63
	5	49.6	.5	2.000	.980	.63
	6	49.1	0	0		0
		Total loss	13.6	Average	0.982	13.96
			(3.4/ha)			(5.6/ha)
10-inch (25.4-cm)	0	38.8	0.8	1.250	0.974	1.09
	1	38.0	1.1	.909	.974	1.46
	2	36.9	3.9	.256	.972	4.79
	3	33.0	10.6	.094	.964	10.38
	4	22.4	1.4	.714	.955	1.09
	5	21.0	.6	1.667	.953	.44
	6	20.4	.2	5.000		.14
	7	20.2	0	0		0
		Total loss	18.6	Average	0.965	19.39
			(7.4/ha)			(7.8/ha)
12-inch (30.5-cm)	0	17.0	0.6	1.667	0.942	0.95
	1	16.4	1.3	.769	.938	1.91
	2	15.1	2.8	.357	.932	3.54
	3	12.3	4.2	.238	.902	4.06
	4	8.1	1.2	.833	.875	.88
	5	6.9	.2	5.000	.863	.13
	6	6.7	.1	10.000		.64
	7	6.6	0	0		0
		Total loss	10.4	Average	0.909	11.87
			(4.2/ha)			(4.7/ha)
14-inch (35.6-cm)	0	8.0	0.4	2.500	0.880	0.89
	1	7.6	1.2	.833	.867	2.28
	2	6.4	2.2	.454	.826	3.07
	3	4.2	2.0	.500	.724	1.88
	4	2.2	.4	2.500	.606	.25
	5	1.8	.2	5.000	.55	.10
	6	1.6	0	0		0
		Total loss	6.4	Average	0.743	8.47
			(2.6/ha)			(3.4/ha)
16-inch (40.6-cm)	0	2.1	0.3	3.333	0.598	0.624
	1	1.8	.3	3.333	5.45	.534
	2	1.5	.7	1.429	.407	.841
	3	.8	.3	3.333	.209	.238
	4	.5	.2	5.000	.078	.105
	5	.3	.1	10.000	.017	.033
	6	.2	0	0		0
		Total loss	1.9	Average	.309	2.375
			(0.8/ha)			(0.9/ha)

(con.)

ble 18. (Con.)

iameter class	Year of infestation	Number of trees per acre Green (G)	Dead (D)	$1/D_t$	q_t[1]	Predicted tree loss
>16-inch	0	2.0	0.3	3.333	0.582	0.63
>40.6-cm)	1	1.7	.4	2.500	.511	.67
	2	1.3	.9	1.111	.270	.88
	3	.4	.1	10.000	.056	.05
	4	.3	.2	5.000	.004	.06
	5	.1	0	0	0	0
	6	.1	0			0
		Total loss	1.9 (0.8/ha)	Average	0.285	2.29 (0.9/ha)
Total	0	211.0	3.0			5.2
	1	208.0	5.0			7.7
	2	203.0	14.0			16.2
	3	189.0	27.0			15.6
	4	162.0	4.0			3.0
	5	158.0	2.0			1.3
	6	156.0	1.0			.2
	7	155.0	0			0
		Total loss	56.0 (22.5/ha)	Average	0.753	59.2 (28.3/ha)

[1] q_t is the probability of a tree not being infested from one source during time, t.

ble 19.—Predicted versus observed tree losses to mountain pine beetles by year based on $\bar{q}_t$, the average probability of tree loss by tree diameter class and stand (Situation A, observed data from Klein and others 1978, grouped by larger diameter classes)

Diameter class	Year of infestation	Number of trees per acre Green (G)	Dead (D)	$1/D_t$	q_t	Predicted tree loss
6 – 12-inch	0	198.3	2.5	0.400	0.997	2.5
15.2 – 30.5-cm)	1	196.8	3.2	.313	.995	3.1
	2	193.6	9.7	.103	.995	9.2
	3	183.9	25.0	.040	.994	21.7
	4	158.9	3.3	.303	.994	2.6
	5	155.6	1.3	.769	.994	1.0
	6	154.3	.3	3.333	0	.2
	7	154.0	0	0		
		Total loss	44.3 (17.7/ha)	Average	0.995	40.3 (16.1/ha)
14 – 16-inch	0	12.1	1.0	1.000	0.917	2.5
35.6 – 40.6-cm)	1	11.1	1.9	.526	.906	3.9
	2	9.2	3.8	.263	.869	5.4
	3	5.4	2.4	.416	.783	2.3
	4	3.0	.8	1.250	.679	.5
	5	2.2	.3	3.333	.613	.15
	6	1.9	0	0	0	0
		Total loss	10.2 (4.1/ha)	Average	0.794	14.8 (5.9/ha)
> 16-inch	0	4.1	0.6	1.667	0.768	1.6
(> 40.6-cm)	1	3.5	.7	1.429	.727	1.7
	2	2.8	1.6	.625	.589	2.0
	3	1.2	.4	2.500	.363	.3
	4	.8	.4	2.500	.177	.2
	5	.4	.4	10.000	.056	.03
	6	.3	0	0	0	0
		Total loss	3.8 (1.5/ha)	Average	0.447	5.9 (2.4/ha)

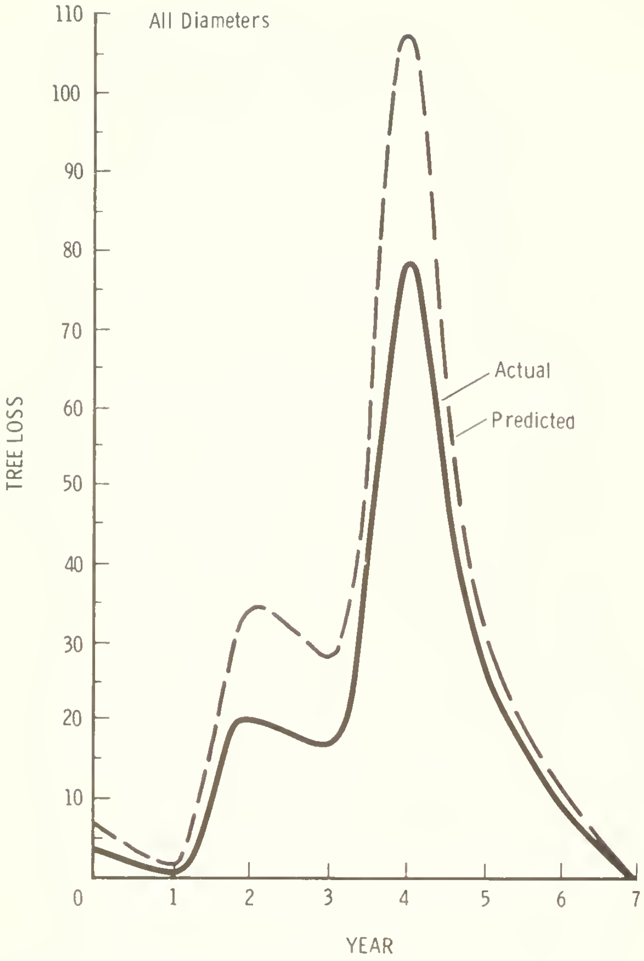


Figure 13.—Predicted versus observed tree losses to mountain pine beetles by year, based on $\bar{q}_t$, by tree diameter class, grouped and total stand (observed losses from Burnell 1977). q_t is the probability of a tree not being infested from one source during time, t.

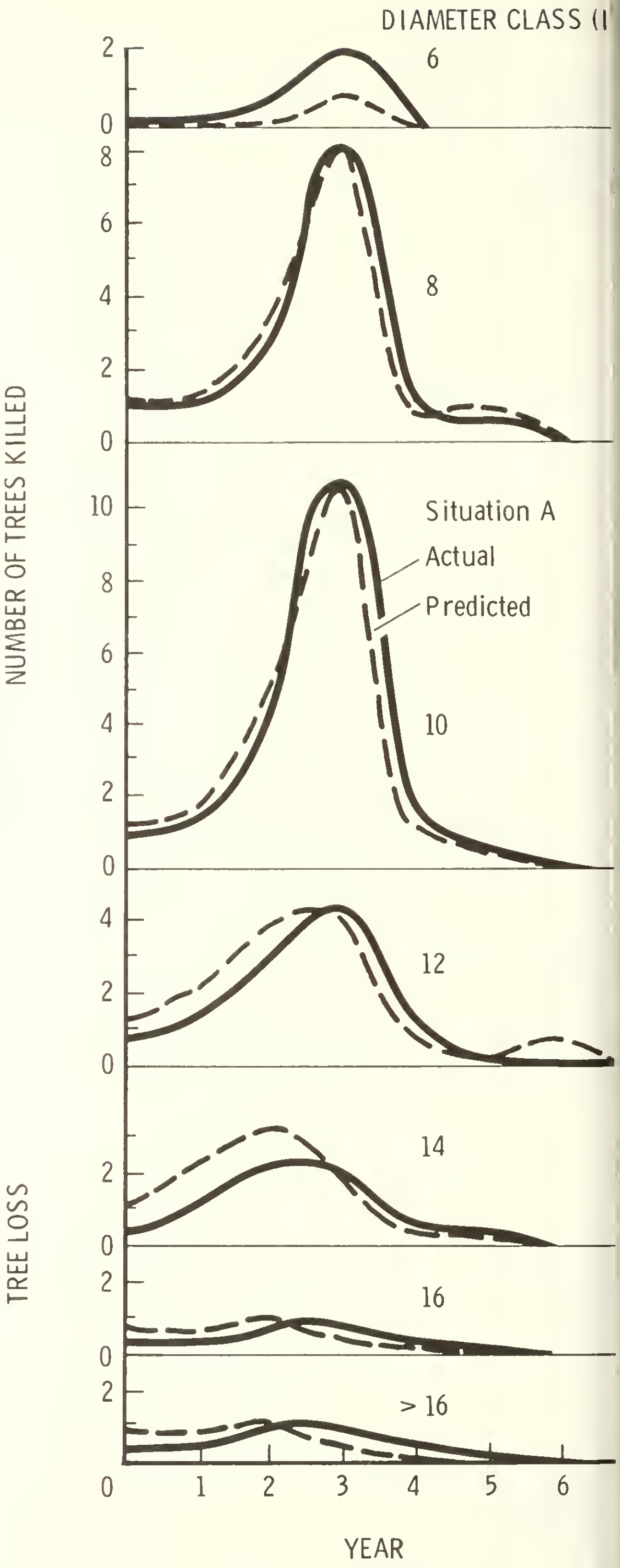


Figure 14.—Predicted versus observed tree losses to mountain pine beetles in lodgepole pine by year, based on $\bar{q}_t$, by 2-inch tree diameter classes (observed losses from Klein and others 1978).

ble 20.—Predicted versus observed tree losses to mountain pine beetles by year based on $\bar{q}_t$, the average probability of tree loss by tree diameter class and stand (Situation B, observed data from Burnell 1977, grouped by total stand)

Year of nfestation	Number of trees per acre Green (G)	Dead (D)	$1/D_t$	q_t	Predicted tree loss
0	370.2	3.6	0.278	0.997	6.6
1	366.6	.8	1.250	.997	1.5
2	365.8	19.5	.051	.997	34.1
3	346.3	16.4	.061	.997	27.3
4	329.9	77.8	.013	.999	106.5
5	252.1	31.8	.032	.992	37.1
6	220.3	10.3	.097	.987	11.1
7	210.0	0	0	0	0
	Total loss	160.2 (64.1/ha)	Average	0.995	224.2 (89.7/ha)

The second data set came from a mountain pine beetle nfestation in the Gallatin River Drainage (Burnell 1977) nd was used only for total tree loss because the data ere not presented by diameter classes. In this data set, tree loss over time did not fall into the usual bell-shaped pattern. However, predicted tree losses approximated the double-peaked curve (table 20) (fig. 15).

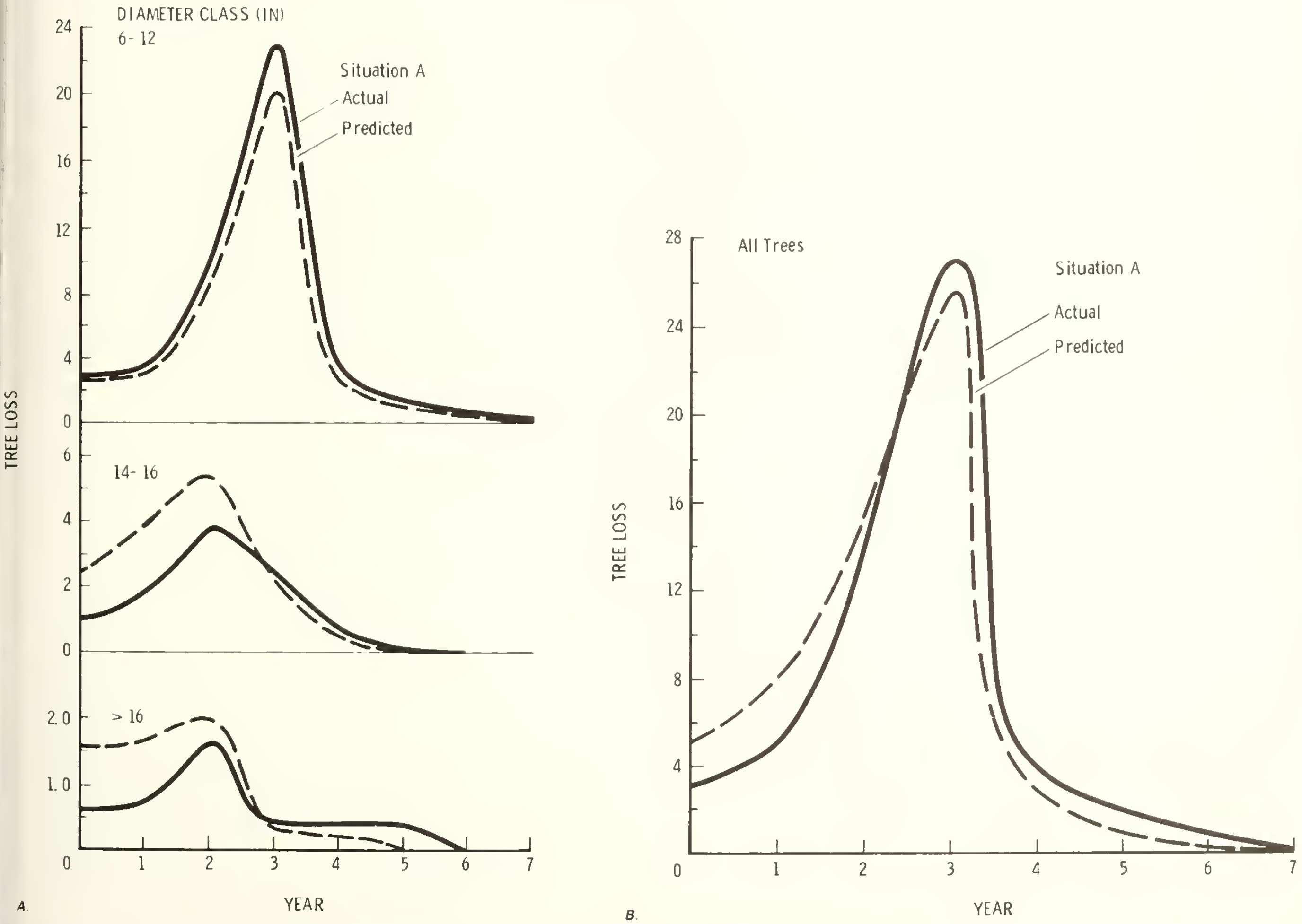


Figure 15.—Predicted versus observed tree losses to mountain pine beetles in lodgepole pine by year, based on $\bar{q}_t$. A. Grouped by tree diameter classes; B. for total stand (observed losses from Klein and others 1978).

Precision of prediction increases with decreasing size of diameter classes; that is, estimates of tree mortality over time approximate true losses closer when predicted by 2-inch (5.1-cm) diameter classes than by larger diameter classes (figs. 13 and 14).

Peak mortality tended to be overestimated when q was large. By the third year of an infestation, q usually becomes small due to the loss of large diameter trees to beetles. Consequently, tree mortality is overestimated. The critical time during an infestation by the mountain pine beetle is at the point of change from endemic to epidemic. The value q applied to the larger diameter trees forecasts the pending infestation adequately, in spite of the tendency toward overestimation.

The model assumes optimum conditions for the life of the epidemic. However, actual field conditions (for example, adverse weather) can cause beetle populations to deviate from predictions. Overestimation of tree mortality is not considered serious in most cases, particularly in the larger diameter classes. Epidemics usually begin in larger diameter trees preferred by the mountain pine beetle, and the rate of tree loss within these classes is critical. Thus, any factor that affects brood survival, such as thick phloem (food supply), which is correlated with larger diameters, will affect the rate of tree loss and, in turn, successive generations.

Linking to INDIDS model.—The INDIDS model (Bousfield 1981) is used to analyze forest insect and disease data collected from variable or fixed plots. It provides summaries of detailed mensurational data of infested and residual green stands, a tree species, size class, and damage class for each designated survey typ The INDIDS model also computes tree and volume losses and basal area killed per acre.

The rate of loss and INDIDS models were linked to e timate mortality trends for stands with ongoing mortality or to obtain loss estimates (tree, cubic, and board-foot volumes) by diameter class over infestation time fo green stands, should they become infested (table 21). The INDIDS/rate of loss model was tested, using approximately 1,200 stands with varying degrees of mountain pine beetle infestation (ranging from 1 year to the end of the epidemic) (McGregor and others 1982).

Table 21.—Estimated trees per acre and volume losses by diameter class over time, using the rate of loss model for mountain pine beetle in lodgepole pine

a. Mixed species stand: 25.4 percent subalpine fir, 12.4 percent Engelmann spruce, 12.4 percent whitebark pine, 37.3 percent lodgepole pine, 12.4 percent Douglas-fir

Item	Diameter at breast height 0-2.9	3-4.9	5-6.9	7-8.9	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19 +	Total
				Lodgepole Pine Trees and Cubic Foot Volume per Acre Before an Outbreak							
Live trees	.00	.00	.00	.00	.00	31.85	31.37	.00	9.32	.00	72.54
Dead trees	.00	.00	.00	.00	.00	1.12	1.57	.00	1.40	.00	4.09
Cubic feet	.00	.00	.00	.00	.00	691.56	943.91	.00	457.15	.00	2,092.62

Trees per Acre Killed During 10-Year Outbreak

	Diameter at breast height																			
	0-2.9		3-4.9		5-6.9		7-8.9		9-10.9		11-12.9		13-14.9		15-16.9		17-18.9		19 +	
Year	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead
1	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00	27.6	3.12	18.7	11.10	.0	.00	1.4	6.55	.0	.00
2	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00	20.5	7.12	.7	18.01	.0	.00	.0	1.37	.0	.00
3	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00	10.4	10.09	.0	.69	.0	.00	.0	.00	.0	.00
4	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00	4.0	6.42	.0	.00	.0	.00	.0	.00	.0	.00
5	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00	2.1	1.82	.0	.00	.0	.00	.0	.00	.0	.00
6	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00	1.8	.34	.0	.00	.0	.00	.0	.00	.0	.00
7	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00	1.7	.06	.0	.00	.0	.00	.0	.00	.0	.00
8	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00	1.7	.01	.0	.00	.0	.00	.0	.00	.0	.00
9	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00	1.7	.00	.0	.00	.0	.00	.0	.00	.0	.00
10	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00	1.7	.00	.0	.00	.0	.00	.0	.00	.0	.00

Lodgepole Pine Trees and Cubic Foot Volume per Acre After an Outbreak

	Diameter at breast height 0-2.9	3-4.9	5-6.9	7-8.9	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19 +	Total	Percent mortality
T/A	.00	.00	.00	.00	.00	1.74	.00	.00	.00	.00	1.74	97.6
CFA	.00	.00	.00	.00	.00	37.72	.08	.00	.00	.00	37.80	98.2

Attack	Unsec	LP Total	Percent
.00	.00	56.54	.00
Attack CFA	Unsec CFA	LPCFV Total	Percent CFV
.00	.00	1,608.99	.00

(con.)

Table 21. (Con.)

b. Mixed species stand: 15 percent lodgepole pine, 85 percent Douglas-fir, subalpine fir, Engelmann spruce

	Diameter at breast height										
Item	**0-2.9**	**3-4.9**	**5-6.9**	**7-8.9**	**9-10.9**	**11-12.9**	**13-14.9**	**15-16.9**	**17-18.9**	**19 +**	**Total**

Lodgepole Pine Trees and Cubic Foot Volume per Acre Before an Outbreak

Item	0-2.9	3-4.9	5-6.9	7-8.9	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19 +	Total
Live trees	.00	.00	.00	.00	6.91	.00	11.46	.00	.00	.00	18.38
Dead trees	.00	.00	.00	.00	.14	.00	.57	.00	.00	.00	.72
Cubic feet	.00	.00	.00	.00	143.42	.00	323.26	.00	.00	.00	466.68

Trees per Acre Killed During 10-Year Outbreak

	Diameter at breast height																			
	0-2.9		**3-4.9**		**5-6.9**		**7-8.9**		**9-10.9**		**11-12.9**		**13-14.9**		**15-16.9**		**17-18.9**		**19 +**	
Year	**Live**	**Dead**	**Live**	**Dead**	**Live**	**Dead**	**Live**	**Dead**	**Live**	**Dead**	**Live**	**Dead**	**Live**	**Dead**	**Live**	**Dead**	**Live**	**Dead**	**Live**	**Dead**
1	.0	.00	.0	.00	.0	.00	.0	.00	6.7	.03	.0	.00	9.2	1.70	.0	.00	.0	.00	.0	.00
2	.0	.00	.0	.00	.0	.00	.0	.00	6.7	.01	.0	.00	5.5	3.65	.0	.00	.0	.00	.0	.00
3	.0	.00	.0	.00	.0	.00	.0	.00	6.7	.00	.0	.00	1.9	3.66	.0	.00	.0	.00	.0	.00
4	.0	.00	.0	.00	.0	.00	.0	.00	6.7	.00	.0	.00	.6	1.24	.0	.00	.0	.00	.0	.00
5	.0	.00	.0	.00	.0	.00	.0	.00	6.7	.00	.0	.00	.4	.19	.0	.00	.0	.00	.0	.00
6	.0	.00	.0	.00	.0	.00	.0	.00	6.7	.00	.0	.00	.4	.02	.0	.00	.0	.00	.0	.00
7	.0	.00	.0	.00	.0	.00	.0	.00	6.7	.00	.0	.00	.4	.00	.0	.00	.0	.00	.0	.00
8	.0	.00	.0	.00	.0	.00	.0	.00	6.7	.00	.0	.00	.4	.00	.0	.00	.0	.00	.0	.00
9	.0	.00	.0	.00	.0	.00	.0	.00	6.7	.00	.0	.00	.4	.00	.0	.00	.0	.00	.0	.00
10	.0	.00	.0	.00	.0	.00	.0	.00	6.7	.00	.0	.00	.4	.00	.0	.00	.0	.00	.0	.00

Lodgepole Pine Trees and Cubic Foot Volume per Acre After an Outbreak

	Diameter at breast height											
	0-2.9	**3-4.9**	**5-6.9**	**7-8.9**	**9-10.9**	**11-12.9**	**13-14.9**	**15-16.9**	**17-18.9**	**19 +**	**Total**	**Percent mortality**
T/A	.00	.00	.00	.00	6.73	.00	.41	.00	.00	.00	7.13	61.2
CFA	.00	.00	.00	.00	139.53	.00	11.51	.00	.00	.00	151.04	67.6

Attack	Unsec	LP Total	Percent
.00	.00	10.45	.00
Attack CFA	Unsec CFA	LPCFV Total	Percent CFV
.00	.00	242.77	.00

(con.)

Table 21. (con.)

c. Mixed species stand: 65 percent subalpine fir, 29 percent Engelmann spruce, 6 percent lodgepole pine

Item	Diameter at breast height 0-2.9	3-4.9	5-6.9	7-8.9	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19 +	Total
Lodgepole Pine Trees and Cubic Foot Volume per Acre Before an Outbreak											
Live trees	.00	60.00	33.67	176.07	30.58	49.86	14.09	12.30	.00	4.11	380.68
Dead trees	.00	.00	.13	2.25	.63	1.76	.70	1.76	.00	.62	7.85
Cubic feet	.00	.00	149.92	1,452.10	417.93	1,271.31	455.69	495.95	.00	247.44	4,490.34

Trees per Acre Killed During 10-Year Outbreak

	Diameter at breast height																			
	0-2.9		3-4.9		5-6.9		7-8.9		9-10.9		11-12.9		13-14.9		15-16.9		17-18.9		19 +	
Year	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead
1	.0	.00	60.0	.00	33.5	.03	166.8	6.97	29.3	.66	40.7	7.44	10.9	2.53	1.3	9.20	.0	.00	1.6	1.88
2	.0	.00	60.0	.00	33.5	.01	147.0	19.85	28.6	.69	20.0	20.66	5.1	5.73	.0	1.34	.0	.00	.2	1.46
3	.0	.00	60.0	.00	33.5	.00	102.5	44.49	27.9	.69	2.8	17.22	.9	4.19	.0	.00	.0	.00	.0	.13
4	.0	.00	60.0	.00	33.5	.00	45.7	56.82	27.2	.68	.5	2.25	.3	.66	.0	.00	.0	.00	.0	.00
5	.0	.00	60.0	.00	33.5	.00	16.3	29.41	26.6	.65	.4	.10	.2	.05	.0	.00	.0	.00	.0	.00
6	.0	.00	60.0	.00	33.5	.00	9.5	6.74	26.0	.61	.4	.00	.2	.00	.0	.00	.0	.00	.0	.00
7	.0	.00	60.0	.00	33.5	.00	8.4	1.10	25.4	.56	.4	.00	.2	.00	.0	.00	.0	.00	.0	.00
8	.0	.00	60.0	.00	33.5	.00	8.3	.17	24.9	.50	.4	.00	.2	.00	.0	.00	.0	.00	.0	.00
9	.0	.00	60.0	.00	33.5	.00	8.2	.03	24.5	.44	.4	.00	.2	.00	.0	.00	.0	.00	.0	.00
10	.0	.00	60.0	.00	33.5	.00	8.2	.00	24.1	.38	.4	.00	.2	.00	.0	.00	.0	.00	.0	.00

Lodgepole Pine Trees and Cubic Foot Volume per Acre After an Outbreak

	Diameter at breast height 0-2.9	3-4.9	5-6.9	7-8.9	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19 +	Total	Percent mortality
T/A	.00	60.00	33.51	8.25	24.10	.43	.22	.00	.00	.02	126.52	66.8
CFA	.00	.00	149.19	68.01	329.32	10.98	7.02	.00	.00	1.25	565.76	87.4

Attack	Unsec	LP Total	Percent
.00	.00	190.20	.00
Attack CFA	Unsec CFA	LPCFV Total	Percent CFV
.00	.00	2,256.65	.00

(con.)

Table 21. (Con.)

d. Mixed species stand: 10 percent subalpine fir, 77.1 percent lodgepole pine, 12.6 percent Douglas-fir

Item	Diameter at breast height										
	0-2.9	3-4.9	5-6.9	7-8.9	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19 +	Total
	Lodgepole Pine Trees and Cubic Foot Volume per Acre Before an Outbreak										
Live trees	94.74	.00	72.32	99.93	48.68	34.83	14.25	3.28	1.14	1.65	370.82
Dead trees	.00	.00	11.47	18.72	11.95	14.48	5.89	.47	1.14	1.65	65.77
Cubic feet	.00	.00	303.49	925.85	775.39	755.39	435.55	137.38	75.42	141.69	3,550.61

Trees per Acre Killed During 10-Year Outbreak

Year	Diameter at breast height																			
	0-2.9		3-4.9		5-6.9		7-8.9		9-10.9		11-12.9		13-14.9		15-16.9		17-18.9		19 +	
	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead
1	94.7	.00	.0	.00	56.5	4.39	57.8	23.41	24.0	12.73	5.1	15.24	1.5	6.91	1.6	1.19	.0	.00	.0	.00
2	94.7	.00	.0	.00	54.9	1.59	37.8	20.02	15.2	8.75	1.2	3.92	.2	1.27	.4	1.22	.0	.00	.0	.00
3	94.7	.00	.0	.00	54.3	.57	26.3	11.52	11.2	4.09	.8	.37	.1	.06	.1	.31	.0	.00	.0	.00
4	94.7	.00	.0	.00	54.1	.20	21.3	4.96	9.7	1.51	.8	.03	.1	.00	.1	.03	.0	.00	.0	.00
5	94.7	.00	.0	.00	54.0	.07	19.5	1.84	9.1	.51	.8	.00	.1	.00	.1	.00	.0	.00	.0	.00
6	94.7	.00	.0	.00	54.0	.02	18.8	.64	9.0	.16	.8	.00	.1	.00	.1	.00	.0	.00	.0	.00
7	94.7	.00	.0	.00	54.0	.01	18.6	.22	8.9	.05	.8	.00	.1	.00	.1	.00	.0	.00	.0	.00
8	94.7	.00	.0	.00	54.0	.00	18.5	.07	8.9	.02	.8	.00	.1	.00	.1	.00	.0	.00	.0	.00
9	94.7	.00	.0	.00	54.0	.00	18.5	.02	8.9	.01	.8	.00	.1	.00	.1	.00	.0	.00	.0	.00
10	94.7	.00	.0	.00	54.0	.00	18.5	.01	8.9	.00	.8	.00	.1	.00	.1	.00	.0	.00	.0	.00

Lodgepole Pine Trees and Cubic Foot Volume per Acre After an Outbreak

	Diameter at breast height											Percent mortality
	0-2.9	3-4.9	5-6.9	7-8.9	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19 +	Total	
T/A	94.74	.00	53.99	18.51	8.91	.79	.13	.06	.00	.00	177.13	52.2
CFA	.00	.00	226.57	171.48	138.38	17.61	3.85	2.70	.00	.00	560.49	84.2

Attack	Unsec	LP Total	Percent
65.31	.00	161.67	40.39
Attack CFA	Unsec CFA	LPCFV Total	Percent CFV
1,118.04	.00	1,709.80	65.39

(con.)

e. Mixed species stand: 28.6 percent subalpine fir, 0.2 percent whitebark pine, 60.6 percent lodgepole pine

Item	Diameter at breast height 0-2.9	3-4.9	5-6.9	7-8.9	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19+	Total
Lodgepole Pine Trees and Cubic Foot Volume per Acre Before an Outbreak											
Live trees	245.45	.00	16.28	8.81	59.05	24.13	3.95	.00	.00	.00	357.66
Dead trees	.00	.00	.06	8.81	26.13	9.93	.20	.00	.00	.00	45.13
Cubic feet	.00	.00	57.19	78.37	840.12	501.31	94.03	.00	.00	.00	1,571.02

Trees per Acre Killed During 10-Year Outbreak

	Diameter at breast height																			
	0-2.9		3-4.9		5-6.9		7-8.9		9-10.9		11-12.9		13-14.9		15-16.9		17-18.9		19+	
Year	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead
1	245.5	.00	.0	.00	16.2	.01	.0	.00	13.0	19.94	5.5	8.69	3.5	.21	.0	.00	.0	.00	.0	.00
2	245.5	.00	.0	.00	16.2	.00	.0	.00	6.4	6.60	2.4	3.10	3.3	.22	.0	.00	.0	.00	.0	.00
3	245.5	.00	.0	.00	16.2	.00	.0	.00	5.0	1.34	1.8	.62	3.1	.21	.0	.00	.0	.00	.0	.00
4	245.5	.00	.0	.00	16.2	.00	.0	.00	4.8	.23	1.7	.10	2.9	.19	.0	.00	.0	.00	.0	.00
5	245.5	.00	.0	.00	16.2	.00	.0	.00	4.8	.04	1.7	.02	2.8	.16	.0	.00	.0	.00	.0	.00
6	245.5	.00	.0	.00	16.2	.00	.0	.00	4.8	.01	1.7	.00	2.6	.13	.0	.00	.0	.00	.0	.00
7	245.5	.00	.0	.00	16.2	.00	.0	.00	4.8	.00	1.7	.00	2.5	.10	.0	.00	.0	.00	.0	.00
8	245.5	.00	.0	.00	16.2	.00	.0	.00	4.8	.00	1.7	.00	2.5	.07	.0	.00	.0	.00	.0	.00
9	245.5	.00	.0	.00	16.2	.00	.0	.00	4.8	.00	1.7	.00	2.4	.05	.0	.00	.0	.00	.0	.00
10	245.5	.00	.0	.00	16.2	.00	.0	.00	4.8	.00	1.7	.00	2.4	.04	.0	.00	.0	.00	.0	.00

Lodgepole Pine Trees and Cubic Foot Volume per Acre After an Outbreak

	Diameter at breast height 0-2.9	3-4.9	5-6.9	7-8.9	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19+	Total	Percent mortality
T/A	245.5	.00	16.21	.00	4.76	1.67	2.38	.00	.00	.00	270.47	24.6
CFA	.00	.00	56.94	.00	67.68	34.60	56.78	.00	.00	.00	216.01	86.3

Attack	Unsec	LP Total	Percent
44.87	.00	278.91	16.09
Attack CFA	Unsec CFA	LPCFV Total	Percent CFV
710.12	.00	1,247.91	56.90

(con.)

Table 21. (Con.)
f. Pure lodgepole pine stand

Item	Diameter at breast height 0-2.9	3-4.9	5-6.9	7-8.9	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19+	Total
					Lodgepole Pine Trees and Cubic Foot Volume per Acre Before an Outbreak						
Live trees	85.71	300.00	141.46	48.95	22.59	.00	.00	8.35	.00	.00	607.07
Dead trees	.00	.00	.54	.63	.47	.00	.00	1.19	.00	.00	2.82
Cubic feet	.00	.00	484.47	459.73	301.62	.00	.00	258.85	.00	.00	1,504.67

Trees per Acre Killed During 10-Year Outbreak

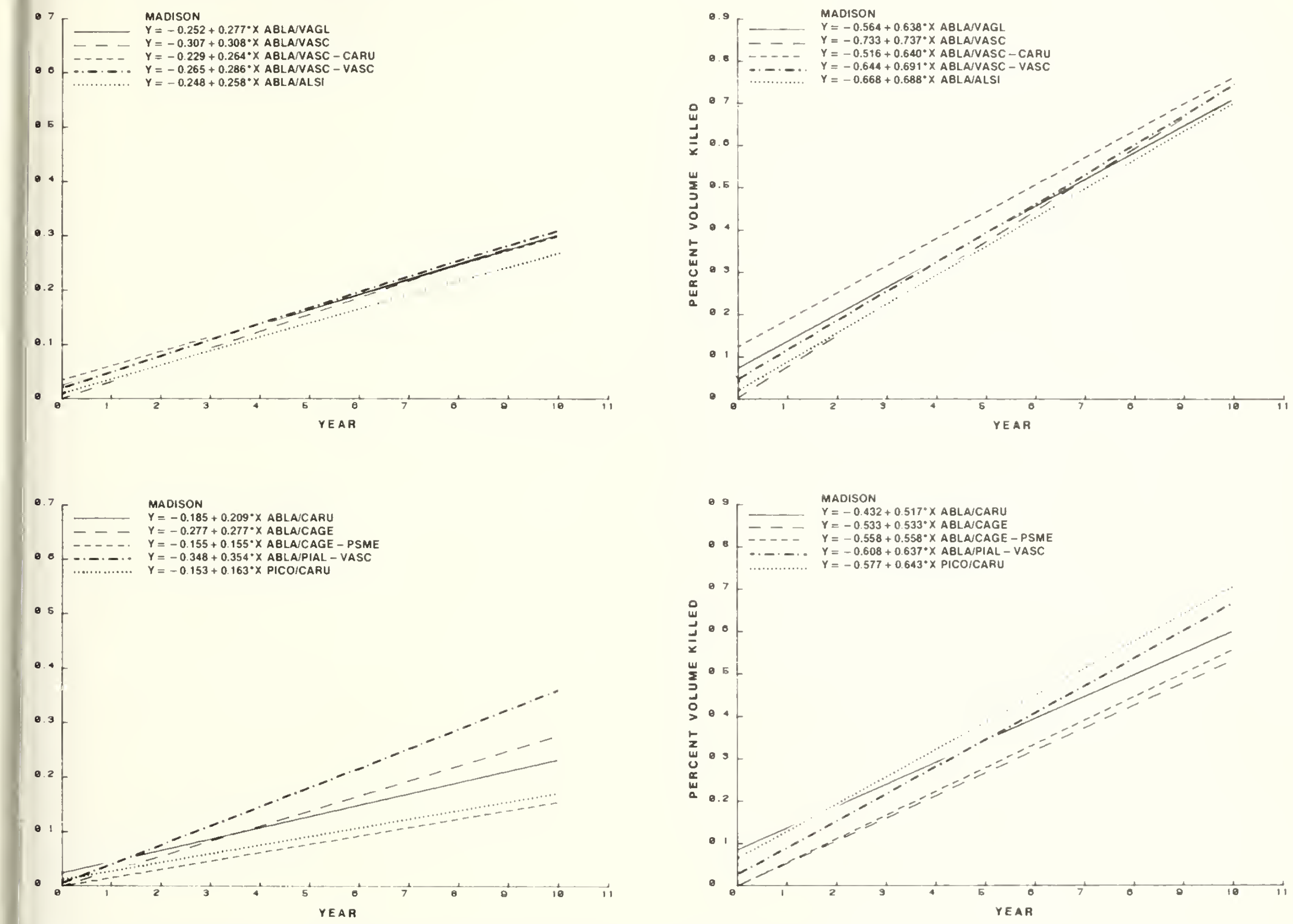
Year	Diameter at breast height 0-2.9 Live	0-2.9 Dead	3-4.9 Live	3-4.9 Dead	5-6.9 Live	5-6.9 Dead	7-8.9 Live	7-8.9 Dead	9-10.9 Live	9-10.9 Dead	11-12.9 Live	11-12.9 Dead	13-14.9 Live	13-14.9 Dead	15-16.9 Live	15-16.9 Dead	17-18.9 Live	17-18.9 Dead	19+ Live	19+ Dead
1	85.7	.00	300.0	.00	140.4	.49	47.8	.55	21.8	.36	.0	.00	.0	.00	1.8	5.39	.0	.00	.0	.00
2	85.7	.00	300.0	.00	140.0	.45	47.3	.47	21.5	.28	.0	.00	.0	.00	.0	1.76	.0	.00	.0	.00
3	85.7	.00	300.0	.00	139.6	.41	46.9	.40	21.3	.21	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00
4	85.7	.00	300.0	.00	139.2	.37	46.6	.34	21.1	.16	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00
5	85.7	.00	300.0	.00	138.9	.34	46.3	.29	21.0	.12	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00
6	85.7	.00	300.0	.00	138.6	.31	46.0	.24	20.9	.09	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00
7	85.7	.00	300.0	.00	138.3	.28	45.8	.20	20.8	.07	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00
8	85.7	.00	300.0	.00	138.0	.25	45.7	.17	20.8	.05	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00
9	85.7	.00	300.0	.00	137.8	.22	45.5	.14	20.7	.04	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00
10	85.7	.00	300.0	.00	137.6	.20	45.4	.11	20.7	.03	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00

Lodgepole Pine Trees and Cubic Foot Volume per Acre After an Outbreak

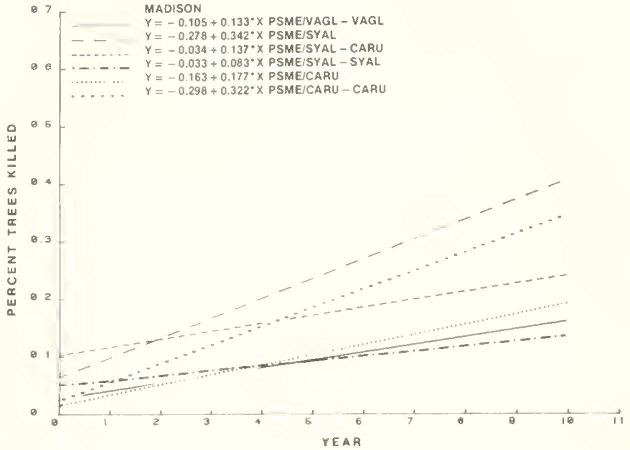
	Diameter at breast height 0-2.9	3-4.9	5-6.9	7-8.9	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19+	Total	Percent mortality
T/A	85.71	300.00	137.60	45.40	20.72	.00	.00	.00	.00	.00	589.43	2.9
CFA	.00	.00	471.24	426.41	276.58	.00	.00	.01	.00	.00	1,174.25	22.0

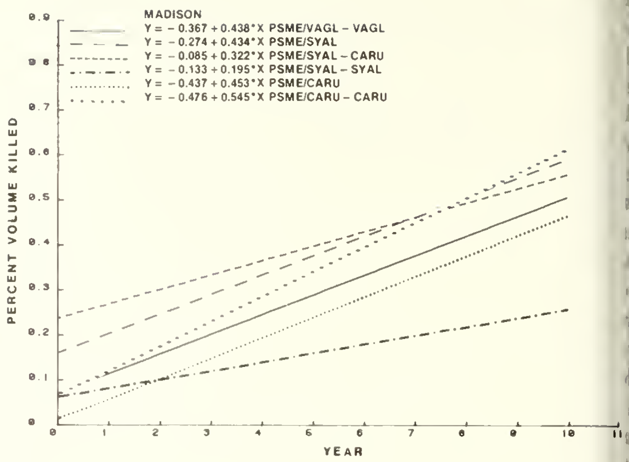
Attack	Unsec	LP Total	Percent
.00	.00	559.90	.00
Attack CFA	Unsec CFA	LPCFV Total	Percent CFV
.00	.00	1,375.11	.00

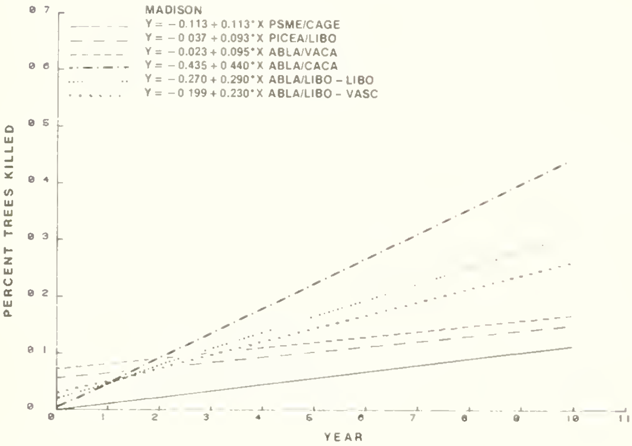
Stand data were then subjected to analysis of variance a d analysis of covariance for completely randomized des n, and graphed to show lodgepole pine mortality by habitat type over time (fig. 16). Analysis shows that the percentage of lodgepole pine killed and volume loss is significantly related to habitat type.

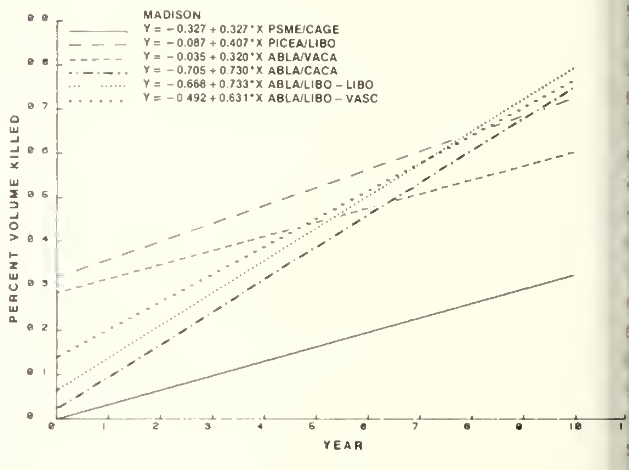


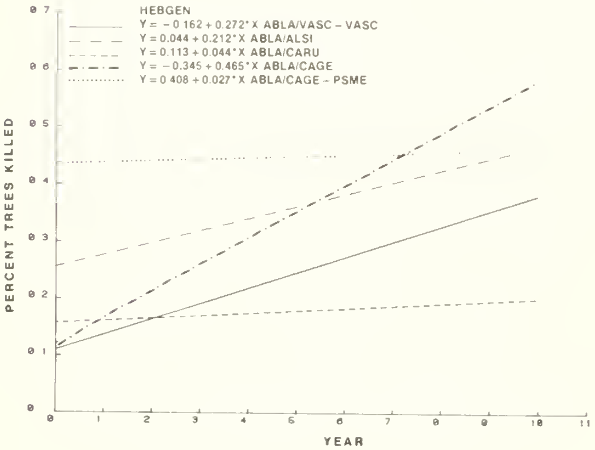
gure 16.—Predicted numbers of lodgepole pine trees and volume losses to mountain e beetles by habitat type over time on the Madison Ranger District, Beaverhead tional Forest, and Hebgen Lake Ranger District, Gallatin National Forest, MT.

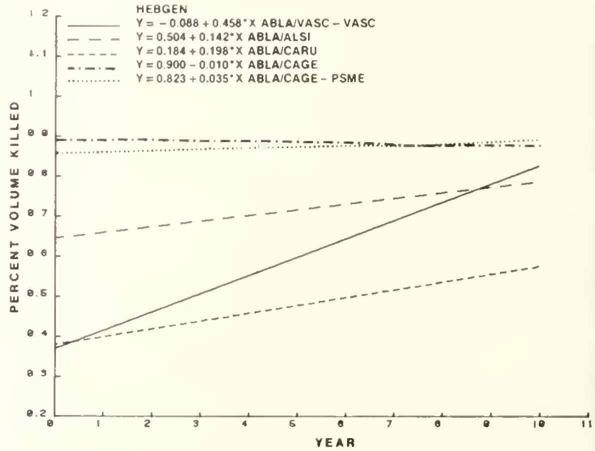

MADISON
Y = − 0.105 + 0.133*X PSME/VAGL − VAGL
Y = − 0.278 + 0.342*X PSME/SYAL
Y = − 0.034 + 0.137*X PSME/SYAL − CARU
Y = − 0.033 + 0.083*X PSME/SYAL − SYAL
Y = − 0.163 + 0.177*X PSME/CARU
Y = − 0.298 + 0.322*X PSME/CARU − CARU
PERCENT TREES KILLED
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
6
7
8
9
10
11
YEAR


MADISON
Y = − 0.367 + 0.438*X PSME/VAGL − VAGL
Y = − 0.274 + 0.434*X PSME/SYAL
Y = − 0.085 + 0.322*X PSME/SYAL − CARU
Y = − 0.133 + 0.195*X PSME/SYAL − SYAL
Y = − 0.437 + 0.453*X PSME/CARU
Y = − 0.476 + 0.545*X PSME/CARU − CARU
PERCENT VOLUME KILLED
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
6
7
8
9
10
11
YEAR


MADISON
Y = − 0.113 + 0.113*X PSME/CAGE
Y = − 0 037 + 0.093*X PICEA/LIBO
Y = − 0.023 + 0.095*X ABLA/VACA
Y = − 0.435 + 0 440*X ABLA/CACA
Y = − 0.270 + 0.290*X ABLA/LIBO − LIBO
Y = − 0 199 + 0.230*X ABLA/LIBO − VASC
PERCENT TREES KILLED
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
6
7
8
9
10
11
YEAR


MADISON
Y = − 0.327 + 0.327*X PSME/CAGE
Y = − 0.087 + 0.407*X PICEA/LIBO
Y = − 0.035 + 0.320*X ABLA/VACA
Y = − 0.705 + 0.730*X ABLA/CACA
Y = − 0.668 + 0.733*X ABLA/LIBO − LIBO
Y = − 0 492 + 0.631*X ABLA/LIBO − VASC
PERCENT VOLUME KILLED
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
6
7
8
9
10
YEAR


HEBGEN
Y = − 0 162 + 0.272*X ABLA/VASC − VASC
Y = 0.044 + 0.212*X ABLA/ALSI
Y = 0.113 + 0.044*X ABLA/CARU
Y = − 0.345 + 0.465*X ABLA/CAGE
Y = 0 408 + 0.027*X ABLA/CAGE − PSME
PERCENT TREES KILLED
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
6
7
8
9
10
11
YEAR


HEBGEN
Y = − 0.088 + 0.458*X ABLA/VASC − VASC
Y = 0.504 + 0.142*X ABLA/ALSI
Y = 0.184 + 0.198*X ABLA/CARU
Y = 0.900 − 0.010*X ABLA/CAGE
Y = 0.823 + 0.035*X ABLA/CAGE − PSME
PERCENT VOLUME KILLED
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
1
2
3
4
5
6
7
8
9
10
11
YEAR

I some habitat types, tree mortality increases ip lly, and most susceptible trees and volume are killed i relatively short time (fig. 17: ABLA/VASC-VASC, E A/ALSI). In others, mortality may occur over 10 ea s and never exceed 30 percent of the stand (fig. 17: E A/CARU, ABLA/LIBO-LIBO). All susceptible trees ia be killed in other habitat types, but it may require t 10 years. Thus, habitat type is an important con- id ation when attempting to predict tree losses.

nowledge of tree losses to mountain pine beetles, by a tat type in conjunction with timber inventory data, a be used to prepare maps showing stands of various a rd to beetle infestation and loss. Historical maps a been used to draw attention to areas that have u ered repeated severe outbreaks of beetles (Crookston n others 1977). Yearly maps prepared for current out- r ks show rate of infestation spread and help delineate t ds of various hazard.

aps prepared from output of the INDIDS/rate of s model can be used by managers to initiate strate- ie to prevent future infestations or to salvage logs and e ce fuel loads in stands where mountain pine beetle i stations have occurred. Usually, managers can ex- e that another epidemic will ensue within 20 to 40 e s, when remaining trees reach size classes with h em thickness conducive to population buildup A man 1975). However, this depends on characteristics f tands and how soon residual trees become suscepti- l For example, management may be postponed until h next decade, if predicted stand mortality does not x ed 20 to 30 percent over 10 years. Meanwhile, t ds can be assessed and management implemented in h se stands containing habitat types and structure v re considerable tree mortality or volume loss is r licted to occur over a short time. By putting the i ier risk stands under management, loss would proba- l be prevented in some high, many moderate, and n y low risk stands.

odel use.—Answers to the questions, "Which of the o gepole pine stands are the most susceptible to moun- a pine beetle outbreak development?" and "How n y trees will the manager lose if a stand becomes in- e ed?" are dependent upon risk. A definition of risk a two components: (1) probability of an outbreak v hin a set time and (2) expected loss in the advent of a outbreak (Safranyik 1982). Reliable methods are not a ilable to predict when an outbreak will develop, but w can predict the most susceptible stands and stand d letion in terms of stand structure.

he Forest Service currently uses FORPLAN, a linear p gramming model (Johnson and others 1980), for land m nagement planning (land use allocation and the s eduling of management activities). The management a ivities and associated outputs, costs, and environmen- t effects used in FORPLAN are presented in prescrip- ti ns for stands within analysis areas. In the Forest S vice Northern Region, analysis areas are lands that n et certain common classification criteria; these lands a not usually contiguous. Classification criteria include h itat type, timber size class, slope class, or other c racteristics.

Using FORPLAN, one approach to modeling tree mortality caused by mountain pine beetles has been to predict susceptible areas in analysis areas, which ones would be affected, and the resulting mortality over two decades. While it might be possible to predict rate of loss from beetles throughout the forest, this information would be of little value for adjusting yield tables if the locations of high, moderate, and low risk stands are not identified within analysis areas. The FORPLAN model would spread bark beetle effects over the next two decades for all stands within analysis areas, which would not allow scheduling earlier harvest of stands with a high probability of infestation and mortality within analysis areas.

An alternative approach is recommended when the locations of stands within analysis areas are identified through timber or stand examination surveys. Beetle attack may then be simulated by the rate of loss model, which shows the effects of an epidemic in the absence of timber management. If other management practices are not implemented, it will be necessary to constrain the predicted tree loss by assignment to a certain acreage. Thus, there would be two prescriptions—one for some stands in parts of the analysis area with infestation, and one for other parts with no effects of infestation.

As an example, stands on the Helena National Forest were analyzed in a FORPLAN run by grouping habitat types so mortality factors could be directly applied to yield tables. A procedure was adopted and used to adjust yield tables based on the coefficients developed for the Helena National Forest plan (Brohman and others 1982). Coefficients were based on the assumption that a 50 percent loss of lodgepole pine would occur over 5 years. If so, then 25 percent of the loss would occur by year 5, and the remaining 75 percent would occur by year 10. The estimated loss as a percentage of volume by age classes was determined as shown:

$$Y_{1'} = Y_1 (1 - \tfrac{1}{4} L)$$
$$Y_{2'} = Y_2 (1 - \tfrac{3}{4} L)$$
$$Y_{j'} = Y_j (1 - L), \; j > 3$$

where

L = proportion of volume lost to beetles (50 percent = 0.50),

Y_j = tabular volume for decade j of the plan, and

$Y_{j'}$ = adjusted volume expected to exist in decade j.

Such coefficients must be derived for each habitat type or habitat type group to be applicable to the model. Note that the decade 1, 2, or 3 of the Forest plan may correspond to different decades in the yield table for different stands or habitat type groups within analysis areas. For example, if groups of stands are 105 years old, then Y_1 is the tabular yield shown at 110 years (25 percent loss by year 5). If the current age is 165 years, then Y_1 is the tabular yield shown for 170 years (25 percent loss by year 5, and 75 percent loss by year 10 at 175 years). The graphs in figure 18 were developed using this approach, coupled with the INDIDS/rate of loss model for the Helena National Forest in the absence of beetle attack. The factor or proportionality is (1−L), the proportion of stand volume not killed.

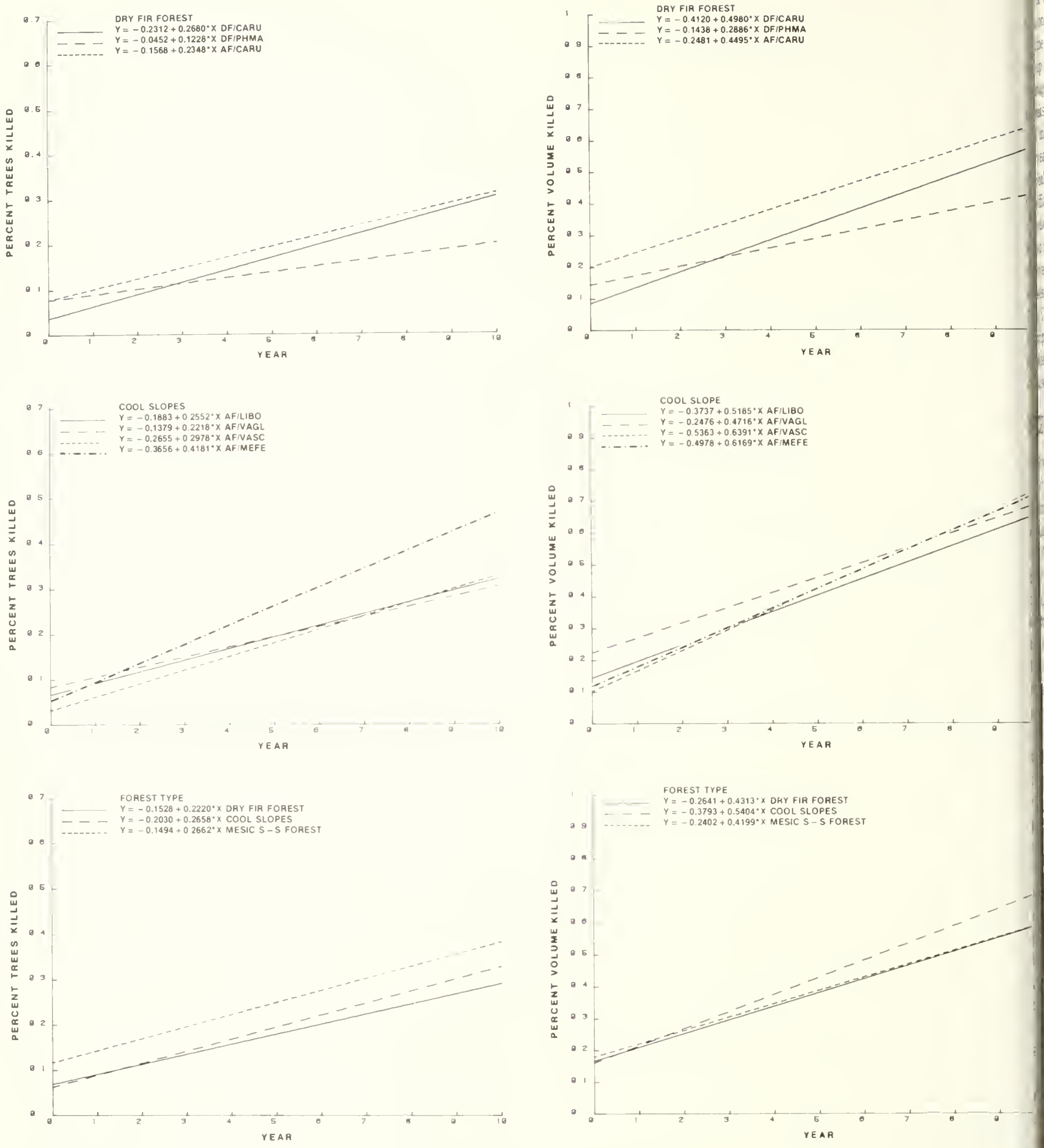


Figure 17.—Projected lodgepole pine tree and volume losses to mountain pine beetles, from the rate of loss-INDIDS model, within habitat type groups on dry cool slopes and mesic sites on Helena National Forest, MT.

he final step in the FORPLAN run for the Helena N:ional Forest plan was to adjust existing yield tables b the appropriate coefficient for each habitat type g up. Regenerated stands were not adjusted, because nagement should prevent mountain pine beetle outb aks over a rotation. The assumption that the beetle wl infest susceptible stands over the Forest in the next 2 years may not be totally correct, but it seems highly p bable, based on available information. By including c fficients in the yield tables, the FORPLAN model s uld show which highly susceptible lodgepole stands n d immediate harvesting, and which stands should be h vested before becoming highly susceptible. By using a essments from FORPLAN and loss predictions from t INDIDS/rate of loss model, harvesting can be acc nplished in high hazard, susceptible stands before an e demic develops, thus minimizing tree mortality c used by beetles.

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APPENDIX

The appendix contains mathematical counterparts of graphic models portrayed in figures 1, 5, 6, and 7. FORTRAN statements from Cole and others (1976) are used for brevity. In the event that highly repetitive computer use is made of the mathematical forms, as in simulation, some added computer efficiency may be achieved with further simplification.

FORTRAN Statements

ENDEMIC GREEN STAND (GS)

```
YR = 1
   GS = 26. 96*EXP(-(ABS(((DBH+18)/
        26.5-1)/.205)**1.8))+.2
LIMIT
  4 ≤ DBH ≤ 30
```

ANNUAL MORTALITY PERCENT (AM)

```
6 ≤ YR ≤ 8
   TI = .235*EXP(-(ABS(((30-DBH)/
        25.5-1)/.225)**1.8))+.365
   EL = EXP(-(ABS(((YR-5.5)/2.5-1)/
        (1-TI))**1.8))
   ER = EXP(-((1/(1-TI))**1.8))
9 ≤ YR ≤ 11
   TI = .055*EXP(-(ABS(((30-DBH)/
        25.5-1)/.35)**3))+.47
   EL = EXP(-(ABS(((11.5-YR)/3.5-1)/
        (1-TI))**1.9))
   ER = EXP(-((1/(1-TI))**1.9))
6 ≤ YR ≤ 11
   YP = .3295*EXP(-(ABS(((DBH-4)/
        26-1)/.8)**4.5))-.0215
   AM = 97.765*YP*((EL-ER)/(1-ER))
LIMITS
  4 ≤ DBH ≤ 30, 1 ≤ YR ≤ 11, integer values only
LIMITS FOR ALL BROOD MODELS
  4 ≤ DBH ≤ 30, 1 ≤ YR ≤ 13, integer values only
```

EGGS (EG)

```
FOR 1 ≤ YR ≤ 11.8
   BP = 177.918*EXP(-(ABS((DBH/35-1)/
        .85)**3))-34.918
   TI = .9533*EXP(-(ABS(((35-DBH)/
        35-1)/.63)**2.6))-.0333
    G = ABS(((YR-1)/10.8-1)/(1-TI))**1.6
    P = 1.6
FOR 11.8 < YR ≤ 13
   BP = 0
   TI = .42*EXP(-(ABS(((35-DBH)/35-1)/
        .605)**5))+.25
    G = ABS(((17-YR)/5.2-1)/(1-TI))**3
    P = 3
FOR 1 ≤ YR ≤ 13
   YP = 349.251*EXP(-(ABS((DBH/35-1)/
        .68)**3.2))-11.251
   ER = EXP(-(1/(1-TI))**P)
   EG = ((EXP(-(G))-ER)/(1-ER)*
        (YP-BP)+BP)**1.0144
```

SMALL LARVAE (SL)

```
FOR 1 ≤ YR ≤ 10
   BP = 50.186*EXP(-(ABS((DBH/35-1)/
        .682)**4.5))-.186
   TI = .105*EXP(-(ABS(((35-DBH)/
        35-1)/.51)**5))+.565
    G = ABS((YR/10-1)/(1-TI))**2.6
    P = 2.6
FOR 11 ≤ YR ≤ 13
   BP = 45*EXP(-(ABS((DBH/35-1)/
        .593)**4))+1
    A = .00025396*(35-DBH)**2.1+.001
   TI = .405*EXP(-(ABS(((35-DBH)/
        35-1)/.146)**2.6))+A
    G = ABS(((13-YR)/3-1)/(1-TI))**2.4
    P = 2.4
FOR 1 ≤ YR ≤ 13
   YP = 98.53*EXP(-(ABS((DBH/35-1)/
        .716)**3.6))-3.53
   ER = EXP(-(1/(1-TI))**P)
   SL = ((EXP(-(G))-ER)/(1-ER)*
        (YP-BP)+BP)*.9565
```

LARGE LARVAE (LL)

```
FOR 1 ≤ YR ≤ 8
   BP = 31.093*EXP(-(ABS((DBH/35-1)/
        .664)**4.3))-.093
   TI = .07598*EXP(-(ABS(((DBH-4)/
        31-1)/.83)**5))+.704
FOR 9 ≤ YR ≤ 13
   BP = 15*EXP(-(ABS((DBH/35-1)/
        .625)**7))+1
   TI = .1073*EXP(-(ABS((DBH/35-1)/
        .674)**3.4))+.708
FOR 1 ≤ YR ≤ 13
   YP = 52.117*EXP(-(ABS((DBH/35-1)/
        .695)**3.7))+.883
   LL = (EXP(—(ABS((YR/8-1)/(1-TI))**
        1.5))*(YP-BP)+BP)*.9865
```

EMERGENCE (EM)

```
FOR 1 ≤ YR ≤ 7
   BP = 17*EXP(-(ABS((DBH/35-1)/
        .655)**6))
    P = 2.3*EXP(-(ABS(((35-DBH)/29-1)/
        .13)**2.2))+2.2
    G = ABS((YR/7.7-1)/.2)**P
FOR 8 ≤ YR ≤ 13
   BP = .13*DBH
   TI = .051/*EXP(-(ABS(((35-DBH)/
        29-1)/.38**7))+.69
    G = ABS((YR/7.7-1)/(1-TI))**1.6
FOR 1 ≤ YR ≤ 13
   YP = 30.328*EXP(-(ABS((DBH/35-1)/
        .715)**4.5))+2.672
   EM = (EXP(-(G))*(YP-BP)+BP)*.995
```

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Cole, Walter E.; Amman, Gene D.; Jensen, Chester E.
Mountain pine beetle dynamics in lodgepole pine forests. Part III: Sampling and modeling of mountain pine beetle populations. General Technical Report INT-188. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station; 1985. 46 p.

This is the last of a three-part series on the mountain pine beetle in lodgepole pine forests. Part III contains original research, a review of published literature primarily on epidemic beetle populations, and sampling and modeling of beetle populations. Sampling methods are available for within-tree populations of beetles, tree losses within stands, and tree losses over large forested areas by aerial means. Models include beetle generation survival, beetle aggregation, lodgepole pine stand-beetle interactions, and rate and amount of tree loss in stands.

KEYWORDS: Scolytidae, *Dendroctonus ponderosae*, *Pinus contorta*, population dynamics, sampling, modeling

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Data Base for Early Postfire Succession on the Sundance Burn, Northern Idaho

Peter F. Stickney

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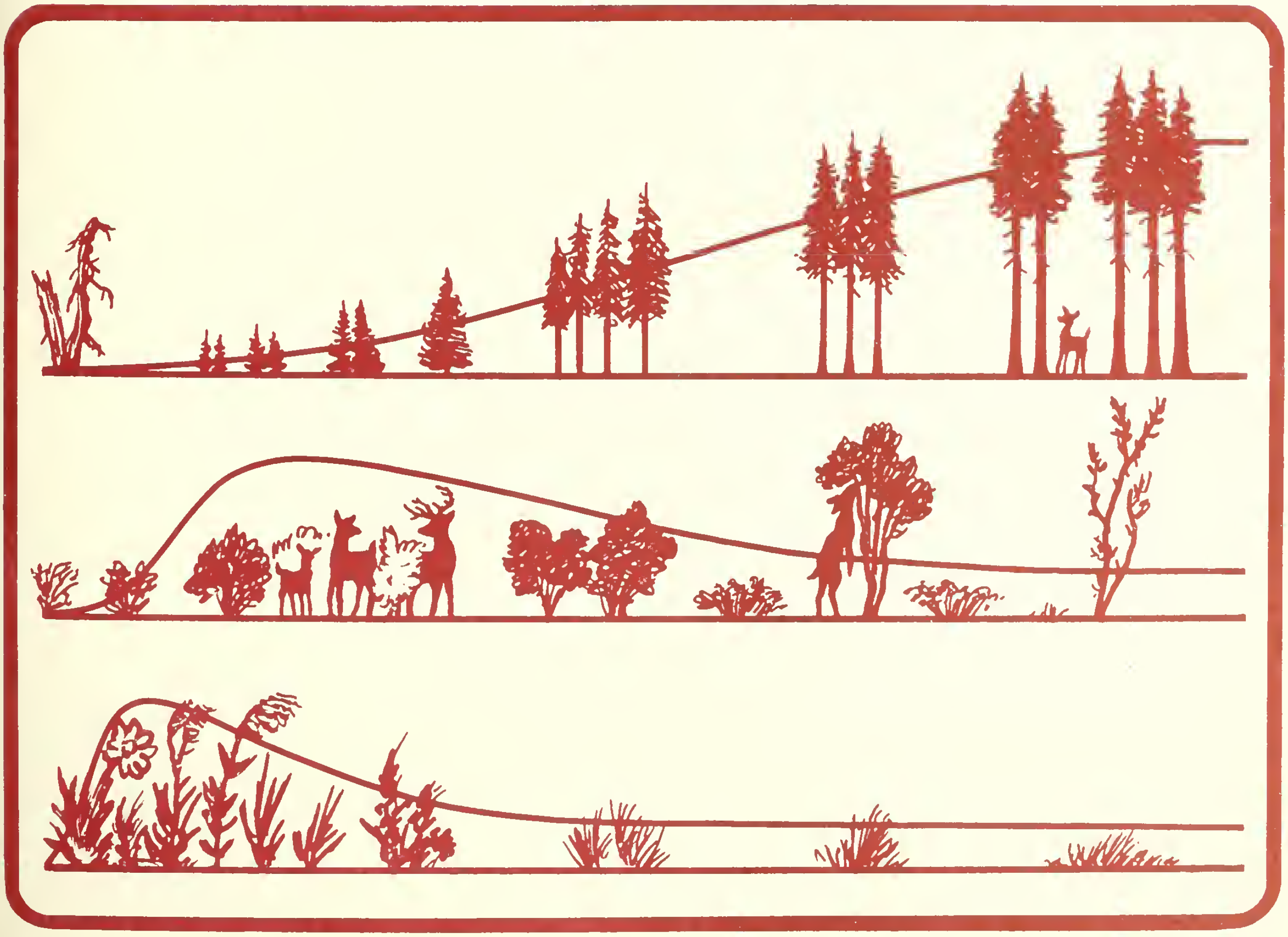

THE AUTHOR

PETER F. STICKNEY, plant ecologist, has served as project scientist on the Northern Rocky Mountains Forest Wildlife Habitats research work unit at Missoula, MT, since its inception in 1962. His work on the plant ecology of upland big game wildlife habitats is principally concerned with the nature and development of seral forest vegetation following disturbance by logging or fire. He was involved in research on mountain grasslands in the Northern Rockies from 1957 to 1962. Prior to this, he did range allotment analysis work on the Malheur National Forest in eastern Oregon. He holds a B.S. degree in forestry from the University of Idaho and an M.S. degree in botany from the University of Wisconsin. He is a member of the Ecological Society of America, Society of Range Management, Northwest Scientific Association, Montana Academy of Sciences, and California Botanical Society.

RESEARCH SUMMARY

Baseline data on herb, shrub, and tree species cover (m^2/0.01 ha) and volume of space occupied (m^3/0.01 ha) for the first 15 years of secondary succession following wildfire in the western redcedar-western hemlock forest type of northern Idaho are presented in tabular form for 18 study areas on the Sundance Burn. These study areas represent an elevational range from 2,900 to 4,300 feet, all cardinal exposures and a range of slopes from 15 to 45 percent. Descriptive information given for each site includes location, prefire forest cover type, postfire reconstruction of prefire tree and shrub components, and intensity and severity of wildfire disturbance.

Information on early successional development is presented in its basic form without interpretation to provide a quantitative resource for modelers working on the development of secondary forest succession and as a source of information on plant species response to fire and the development of seral vegetation for application to forest and wildlife habitat management problems.

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Data Base for Early Postfire Succession on the Sundance Burn, Northern Idaho

Peter F. Stickney

INTRODUCTION

Fire has been a natural and integral part of Northern Rocky Mountain coniferous forests for at least the last 10,000 years (Mehringer and others 1977; Mutch 1970). Recent studies documenting the recurrence of fire in these forests (Arno 1976, 1980; Arno and Davis 1980; Hemphill 1983) suggest most of the forest plant species have evolved or at least existed in the presence of periodic disturbance by fire (Habeck and Mutch 1973; Howe 1976). In fact, many of these plant species exhibit adaptations to survive burning by forest fires (Lyon and Stickney 1976; Bradley 1984). The natural recovery or secondary succession of forest vegetation in the Northern Rocky Mountains following disturbance by wildfire results from a combination of plant species adapted to survive fire in place and those adapted to colonize the immediate postfire site. Severity of fire treatment (Rowe 1983; Ryan and Noste 1985; Viereck and Schandelmeier 1980) to the prefire vegetation directly influences the composition and amount of the survivor component. It also conditions the suitability of the site for germination and establishment of the colonizer component. The early successional development (1 to 15 years) of vegetation presented for the Sundance Burn study areas encompasses a variety of combinations for these two components that range from communities composed largely of survivors (SD−17, SD−21) to those formed predominantly of colonizers (SD−06, SD−07).

To effectively use secondary forest succession processes in achieving forest management objectives requires a fundamental understanding of the response and behavior of at least the important plant species comprising the early postdisturbance forest communities. Quantitative data on postwildfire changes in species abundance through time not only provide the means for determining natural seral development, but also serve as a basis for comparing and evaluating effects of timber harvest and other forms of cultural disturbance on species maintenance. The response of early seral vegetation to disturbance affects a wide variety of forest management activities including the establishment and survival of transplanted tree seedlings, the composition and duration of big game browse ranges, the amount of vegetative cover affording watershed protection, the character of small mammal and songbird habitats, and the production and accumulation of forest fuels.

As management intensifies to meet the increasing demands made of forest wildlands, some of the potential uses for basic plant successional information include:

- designing silvicultural and fire prescriptions to achieve specific management treatment results
- assessing rehabilitation needs following wildfire and aiding in fire damage appraisals
- evaluating probable vegetation recovery for escaped fire analysis
- assessing effect of fire on vegetation for fuels management planning
- developing fire management prescriptions to restore and maintain fire as a natural process in wilderness forest ecosystems
- constructing, testing, and improving models of secondary forest succession.

Most studies of forest succession in the Northern Rocky Mountains employ synthetic reconstructions of community change derived from sampling forest stands of different ages. This approach describes forest succession as it is perceived rather than as it is observed to occur. Inherent variability in initial composition and previous history of stands combined with fragmentary representation of time (stand ages available) provide interrupted and incomplete representations of species' presence and development, which permit only the most generalized reconstruction of forest succession. Also, lack of a continuous record of onsite changes in composition and development prevents recognition of coherent species development patterns that collectively constitute the successional sequence. This is particularly true for the plants that form the initial vegetation following disturbance and the herbs and shrubs that later comprise most of the early seral vegetation. Analytical presentation of most forest succession data for our region obscures its basic quantitative character and thus precludes its direct application to other wildland management problems.

The purpose of this publication is to make basic data on secondary plant succession available in a form that has wide application to the problems associated with the early stages of forest succession development. The results serve as a data base for examining the initial occurrence, response, and development of individual species following wildfire. Cover (crown area) and aerial crown volume (volume of space occupied) of tree, shrub, and herb components were sampled annually on permanent plots following wildfire in standing timber and clearcuts. The tabular presentation of data represents the first 15 years of secondary plant succession on 18 study areas in the Sundance Burn in northern Idaho.

STUDY AREA

On September 1, 1967, the Sundance Fire burned a 16- by 5-mile (26- by 8-km) swath northeastward across the central portion of the Selkirk Range in northern Idaho (fig. 1). The study location is centrally situated within the burn where the fire reached "fire storm" proportions (Anderson 1968). This locale is on the Sandpoint Ranger District, Kaniksu National Forest (lat. 48°34′ N., long. 116°37′ W.) 20 miles (32 km) north of Sandpoint, ID. Specific location within the Pack River drainage of the 18 study areas is shown in figure 2. Elevation of these study areas ranged from 2,950 to 4,300 feet (900 to 1 310 m) and the areas represent all cardinal exposures.

The climate is characterized by long, cool, but not cold, moist winters and short, warm, and dry, but not particularly droughty summers (Finklin 1983). Annual precipitation is estimated between 40 to 60 inches (102 to 152 cm) (Rice 1971) with about three-fourths falling as snow. Topography of the mid- and lower slopes of the Pack River Valley has been rounded and smoothed by mountain glaciation (Alden 1953). Soil is regosolic in character with silt loam texture developed from granitic tills overlain by a loess mantle 6 to 30 inches (15 to 76 cm) thick (USDA Forest Service, n.d.).

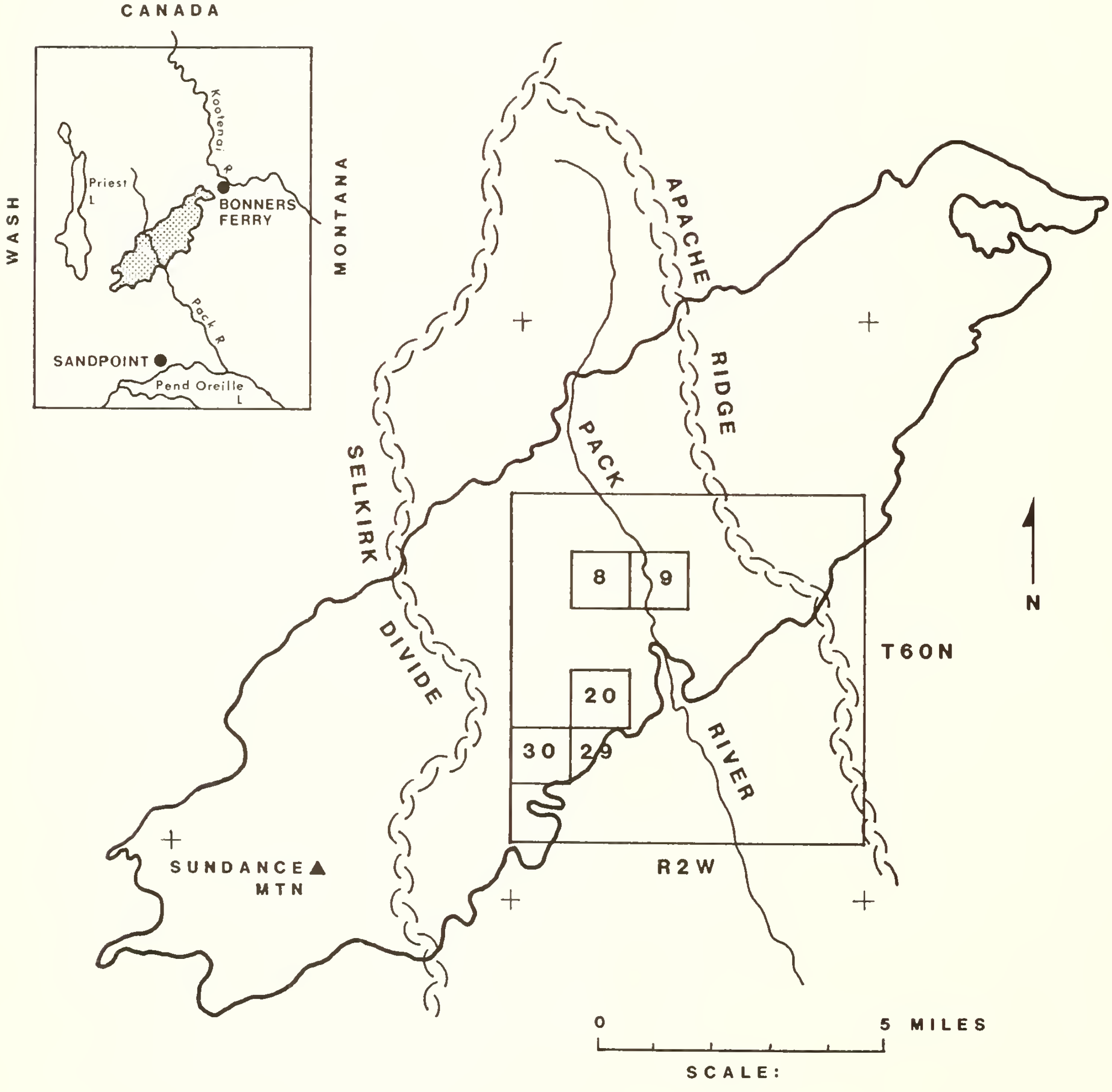

Figure 1.—Sundance Fire in the Selkirk Range of northern Idaho showing the township and section locations containing study area sites.

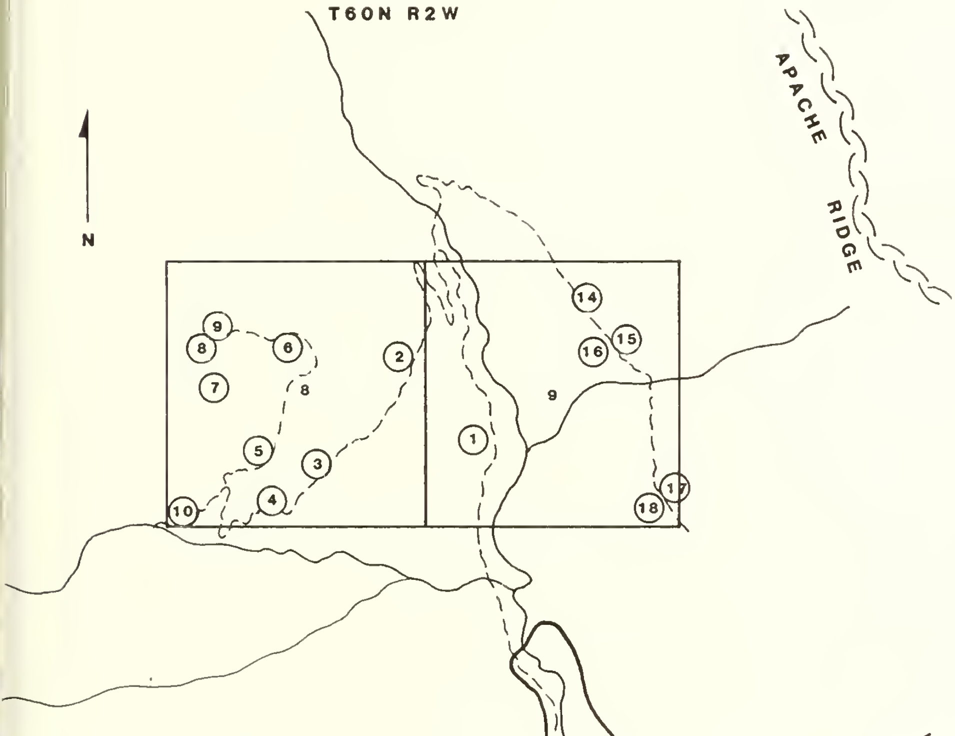

Figure 2.—Sundance Burn study area locations in the Pack River drainage of the Selkirk Range.

Prefire forests on the study areas predominantly contained immature poletimber size trees, 5 to 9 inches (12.7 to 22.6 cm) diameter at breast height (d.b.h.), of the western larch (*Larix occidentalis*) and Douglas-fir (*Pseudotsuga menziesii*) timber types. Most tree crown canopy coverage ranged from 40 to 70 percent (USDA Forest Service 1962). Other timber types represented include mature sawtimber, >9 inches (>22.6 cm) d.b.h., of western redcedar (*Thuja plicata*) and western hemlock (*Tsuga heterophylla*) in the 70 to 100 percent tree canopy cover class. Postfire approximation of forest habitat types suggests that study areas were in the *Thuja-Tsuga* climax forest zone (Daubenmire 1952), and all but the most xeric sites represent the *Tsuga heterophylla-Pachistima myrsinites* habitat type (Daubenmire and Daubenmire 1968).

METHODS

The successional development of vascular plant species was measured on permanent plots using nondestructive sampling techniques. This approach attempts to quantify actual changes in vegetation as they develop in place over time, thereby minimizing extraneous variation in time development of plant species composition and abundance. All plot sampling measurements were metric.

Plot Layout and Vegetation Sampling

The area sampled for each study area consisted of two 5- by 25-m transects, each of which was divided into five contiguous 5- by 5-m blocks (fig. 3). The vegetation was stratified in each block according to life form and height and sampled in four sizes of nested plots (fig. 4). The combination of plant heights and life form associated with each nested plot is given in table 1.

Trees and shrubs over 0.4 m high were sampled on the three larger plots (1.5-, 3-, and 5-m squares). For trees 2.5 m and taller, the d.b.h. (height 1.4 m) was measured in centimeters and recorded by species. Trees 1.5 to 2.5 m high were counted and recorded by species and assigned an assumed d.b.h. of 1.25 cm. Trees 0.5 to 1.5 m in height were counted and recorded by species. All shrubs and trees 0.5 m and taller were measured in decimeters for two horizontal dimensions of the aerial crown and the height above the rooted point.

Herbaceous and low woody plants (including trees and shrubs less than 0.5 m in height) were sampled in two 0.5- by 0.5-m plots located along the baseline within each block (fig. 4). Cover was determined visually by species in units to the nearest one-sixth of the plot, 0.04167 m^2 (fig. 3). Species with individual coverages of less than one-sixth were recorded as miscellaneous vegetation for that plot if they collectively totaled at least one-sixth of the plot area.

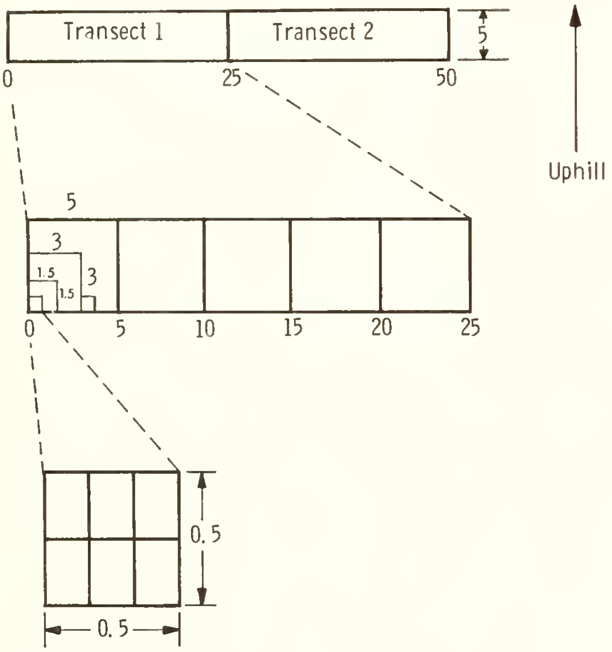

Figure 3.—Field layout of permanent transect pairs showing position and orientation of contiguous blocks and nested plots (dimensions in meters).

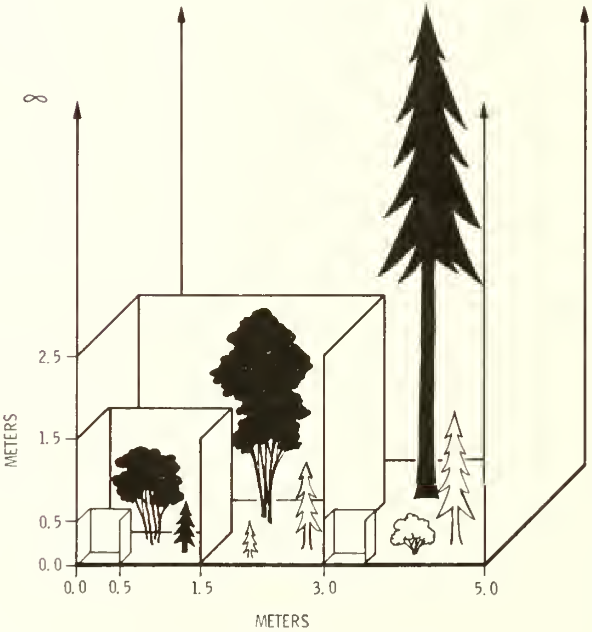

Figure 4.—Height limits of shrubs and trees sampled in nested plots (sample plants, shaded; nonsample plants, outlined).

Table 1.—Summary of plots sampled on each study area

Plot size	Height limits	Vegetation sampled	No./area
------ *Meters* ------			
5 by 5	2.5+	Trees and shrubs	10
3 by 3	1.5–2.45	Trees and shrubs	10
1.5 by 1.5	0.5–1.45	Trees and shrubs	10
0.5 by 0.5	<0.5	Trees and shrubs and all herbs and low woody plants irrespective of height	20

The remaining ground surface not covered by herbaceous or low woody plants was then similarly classified in order as: (1) moss, (2) litter, (3) rock, and (4) bare ground. Cover estimates for this plot were designed to equal 100 percent; therefore coverage values of these four categories represent only that portion not covered by herbaceous or low woody vegetation. The "representative" height within the plot for each species receiving a cover estimate was measured to the nearest half decimeter. Occurrence (absolute frequency) was recorded for each herb and low woody plant species present within this smallest plot. Field sampling for most years was done during the latter part of July through the first half of August.

Vegetation Description

Five attributes descriptive of vegetation can be derived from this sampling method (table 2). Of these, cover (aerial crown area) and crown volume (space occupied by the plant) are considered the most descriptive for representing the early seral development of vegetation. Cover for tree and shrub species was computed using the horizontal crown dimensions as axes of an ellipse. Crown area for herbs and low woody plants was estimated directly in units of cover. Aerial crown volume for trees and shrubs was determined for each individual plant from its crown area and height. The product of these values gives the volume of a cylindroid representing the space occupied by the plant in the community. Similarly, the volume of space occupied by herbs and low woody plants was calculated from the area and representative height. Cover and volume values were averaged by species for each plot size, converted to 0.01 ha base and totaled to produce the tabular value given for each species and life form group. Because this base equals 100 m^2, the values given for cover in the tables may be read directly as percentage of ground cover as well as m^2/0.01 ha. Tabular values for volume are expressed as m^3/0.01 ha.

Table 2.—Attributes describing vegetation development

Vegetative life form	Attribute
Trees (1.5+ m ht)	Density (N/0.01 ha) Basal area (cm^2/0.01 ha)
Shrubs and trees (0.5+ m ht)	Density (N/0.01 ha) Cover (m^2/0.01 ha) Crown volume (m^3/0.01 ha)
Herbs and low woody plants (including tree and shrub species <0.5 m ht)	Frequency (percent) Cover (m^2/0.01 ha) Crown volume (m^3/0.01 ha)

Height, while not presented as tabulated information, may be obtained for any given species from the quotient of its corresponding volume and cover values. The result is mean height in meters. This expression of vertical development can be used to identify the periods required for woody plant species to reach and sustain mature stature in the successional progression.

Nomenclature for vascular plants follows Hitchcock and Cronquist (1973). Plant species identifications were made by the author with verification of many of the species by Drs. Frederick J. Hermann and Charles Feddema, both of the former USDA Forest Service Herbarium at Washington, DC, and later Fort Collins, CO. Voucher specimens for most species are on file at the Forestry Sciences Laboratory Herbarium (MRC), Missoula, MT.

DATA BASE

The data base documents the initiation and early development of seral vegetation for 18 study areas in the "cedar-hemlock" type of northern Idaho. For each study area the data base consists of (1) initial postfire plant species composition, (2) subsequent cover and volume development of vegetation and cover plant species, (3) physical site characteristics, (4) disturbance treatment from wildfire, and (5) representation of prefire vegetation and its species composition.

Initial Vegetation

Species present in the first postfire growing season represent the initial vegetation (appendix) and provide the floristic basis from which the development of early seral vegetation commences. The response to fire of species comprising this initial vegetation is classified in the appendix as either survivor (regrowth or resprouts from burned plants) or colonizer (first-year seedlings). For those species that demonstrated more than one response or adaptation to fire, both are given. In a few instances the charred remains of herbaceous plants were identifiable, and where all plants of a given species on a study area were killed, they are listed as "nonsurvivor." The ability of a plant species to survive fire varies and is related (in part) to the severity of the burning treatment. For this data base those species classified "survivor" demonstrated the capability to survive a fire treatment as severe as a stand-replacing wildfire.

This classification also provides some information on the source or postfire origin of the initial vegetation species. Survivors derive from burned onsite origins. Colonizer origin may be either on site or from outside the burned area. Seed form as related to dispersibility may provide clues as to colonizer origin. The potential for secondary colonization of species from onsite sources is related to its capacity to flower early in succession. Species flowering in the first postfire growing season from either survivor or colonizer plants are indicated in the appendix.

Succession Data Base Tables

For each study area, cover and volume data are presented in a series of six data base tables. Each table is accompanied by a graph illustrating its important elements. Tables 1 and 2 present cover and volume respectively of the seral community life forms; tables 3 and 4 present species composition for cover within life form component; and tables 5 and 6 present volume. Identity of species listed in these tables as four-letter abbreviations of genus and species is given in the appendix.

A few species included in the herb data base tables have often been treated as shrubs. In fact, they are "low woody plants" and lack the morphological traits characteristic of shrubs except one, the presence of perennial stems above ground in the dormant season. Their life form relegates them to the ground layer vegetation rather than the shrub strata above the forest floor. Species treated as low woody plants in the herb tables are *Berberis repens* and *Pyrola secunda*.

Site and Treatment Information

To facilitate communication between users and application of future results the succession data base is referenced to research study 1802−16 of Research Work Unit FS-INT-1705, Forestry Sciences Laboratory, Missoula, MT. Study areas are designated SD−01 through SD−10 and SD−14 through SD−21.

Succession data for each study area are supplemented by a reference section containing information on location, site features (elevation, exposure, and slope), prefire vegetation, and disturbance treatment. Information on prefire vegetation consisted of a timber inventory (USDA Forest Service 1962). Inventory types provided a general characterization of composition, size, and coverage of the predominant or potential (for unstocked sites) prefire tree overstory. A reconstruction from the charred remains of shrubs and trees evident in the first postfire growing season served to further characterize the woody plant component of the prefire vegetation. Tree density and stand basal area were approximated from a sample in the first postfire year of all standing snags in the 5-m square plots. Snag d.b.h. was measured in centimeters. Coniferous snags were sampled as a general entity and therefore not identified as to species. Relative density of surviving shrub species was determined by a count of all resprouting shrubs at least 0.5 m high in the 5-m square plots. Information on prefire shrub species composition was further extended by noting those species regrowing within but not sampled in the 5-m square plots as well as in the vicinity immediately adjacent to these plots. These unsampled prefire species are listed as "other species present." Nonresprouting charred shrub remnants were not sampled; thus, the reconstruction provides only a minimum representation of the prefire shrub community. Species composition for the prefire herbaceous component is not presented, but a minimal approximation of the prefire composition can be obtained by noting the survivor and nonsurvivor species designated for each study area in the appendix.

Information providing an indication of the conditions from which the development of secondary forest succession commenced include evidence of prefire timber cutting and fire disturbance. From postfire observation, prefire overstory appeared undisturbed by cutting or logging except for the two instances noted. Time since cutting was undetermined.

Wildfire disturbance of study areas is described by fire intensity, rate of heat released at the fire front (Albini 1976; Viereck and Schandelmeier 1980), and fire severity, heating sustained by the site (Ryan and Noste 1985). Fire intensity data from Anderson's (1968) reconstruction of the Sundance Fire provides a measure of fire disturbance to the forest vegetation. All values reported by Anderson greatly exceed the minimum limit for high intensity fire defined by Sando (1978) as average intensity greater than 1,200 Btu/sec/ft. Fire severity is more indicative of the disturbance treatment sustained by the vegetation (Rowe 1983) because it incorporates the downward heat pulse to ground layer vegetation and propagules and adventitious buds in the forest floor and soil (Ryan and Noste 1985), as well as the upward heat pulse (fire intensity) to vegetation. Ryan and Noste's (1985) fire severity matrix provides a relative standard that permitted postfire assessment of severity drawn from the degree of ground char and flame length. The matrix comprises four ground char classes (U = unburned; L = light; M = moderate; D = deep) and five flame length classes (1 = 0−2 ft; 2 = 2−4, 3 = 4−8; 4 = 8−12; 5 = >12). Ryan and Noste's fire severity index ranges from 1-U (least severe) to 5-D (most severe). As an example, a fire rated at a severity of R-N index 5-M represents a burning treatment with a flame length exceeding 12 feet and moderate ground char; i.e., duff completely consumed to mineral soil, logs deeply charred, lateral tree roots pedestaled. Observed immediate postfire condition of the forest floor—litter and duff layers (USDA Forest Service 1956)—and tree or shrub overstory are included to permit reference with other indices of fire severity.

SUMMARY OF STUDY AREA CHARACTERISTICS

Site characteristics represented in the succession profiles for the 18 Sundance Burn study areas include physical site features, predisturbance vegetation, and disturbance type (table 3).

The physical characterizations of site are elevation, exposure of slope, and steepness of slope. The number of study areas falling within each 500-foot (150-m) contour interval is:

No. of study areas	500-foot (150-m) interval
1	2,500 to 3,000 feet
5	3,000 to 3,500 feet
6	3,500 to 4,000 feet
6	4,000 to 4,500 feet

Table 3.—Sundance study area site characteristics

Study area	Elevation	Exposure		Slope	Cover type[1]	Tree size[2]	Overstory cover class	Disturbance treatment[3]
	Ft	*Dir.*	*Az°*	*Pct*	*spp.*		*Percent*	
SD – 01	2,950	E	100	20	LAOC	Seedling-sapling	40 – 69	WF
SD – 02	3,300	E	90	20	LAOC	Immature poletimber	40 – 69	WF
SD – 03	3,550	E	110	35	LAOC	Immature poletimber	40 – 69	WF
SD – 04	3,700	S	180	30	LAOC	Immature poletimber	40 – 69	WF
SD – 05	3,950	E	110	25	LAOC	Immature poletimber	40 – 69	WF
SD – 06	4,200	N	355	30	TSHE	Mature sawtimber	40 – 69	WF
SD – 07	4,300	E	130	15	THPL	Mature sawtimber	70 – 100	CC/WF
SD – 08	4,150	N	320	50	TSHE	Mature sawtimber	40 – 69	CC/WF
SD – 09	4,100	N	0	45	TSHE	Mature sawtimber	40 – 69	WF
SD – 10	4,050	S	160	30	LAOC	Immature poletimber	40 – 69	WF
SD – 14	3,400	W	270	40	PSME	Immature poletimber	70 – 100	WF
SD – 15	3,450	W	225	30	PSME	Immature poletimber	70 – 100	WF
SD – 16	3,350	W	240	30	PSME	Immature poletimber	70 – 100	WF
SD – 17	3,650	W	240	30	LAOC	Immature poletimber	10 – 39	WF
SD – 18	3,550	W	245	35	LAOC	Immature poletimber	10 – 39	WF
SD – 19	4,250	E	115	25	PIMO	Immature poletimber	70 – 100	WF
SD – 20	3,800	N	340	40	PIMO	Immature poletimber	70 – 100	WF
SD – 21	3,450	S	165	25	PSME	Unstocked	< 10	WF

[1] Dominant timber species: LAOC = *Larix occidentalis*, PIMO = *Pinus monticola*, PSME = *Pseudotsuga menziesii*, THPL = *Thuja plicata*, TSHE = *Tsuga heterophylla*.

[2] Tree size classes: sawtimber (9+ inches d.b.h.), poletimber (5 to 9 inches d.b.h.), seedling and sapling (<5 inches d.b.h.), unstocked (tree size unstated, few trees present).

[3] WF = wildfire; CC = clearcut.

Cardinal exposures are represented as follows:

No. of study areas	Exposure
4	North
6	East
3	South
5	West

Steepness of slope (5 percent intervals) varied from 15 to 50 percent. Grouped in intervals of 20 percent for gentle, moderate, and steep slope, the representation is:

No. of study areas	Slope
1	Gentle (0 to 20 percent)
13	Moderate (20 to 35 percent)
4	Steep (35+ percent)

Prefire vegetation of study areas described by timber cover types (USDA Forest Service 1962) represents three tree size classes—seedling and sapling, immature poletimber, and mature sawtimber, and four overstory cover classes—< 10 percent, 10 to 40 percent, 40 to 70 percent, and 70 through 100 percent, as follows:

No. of study areas			Cover type (tree size and overstory cover class)
8			*Larix occidentalis*
	(1)		(Seedling and sapling size class)
		(1)	(40 to 70 percent crown coverage)
	(7)		(Immature poletimber size class)
		(5)	(40 to 70 percent crown coverage)
		(2)	(10 to 40 percent crown coverage)
2			*Pinus monticola*
	(2)		(Immature poletimber size class)
		(2)	(70 through 100 percent crown coverage)
4			*Pseudotsuga menziesii*
	(3)		(Immature poletimber size class)
		(3)	(40 to 70 percent crown coverage)
	(1)		(Unstocked tree class)
		(1)	(< 10 percent crown coverage)
1			*Thuja plicata*
	(1)		(Mature sawtimber size class)
		(1)	(70 through 100 percent crown coverage)
3			*Tsuga heterophylla*
	(3)		(Mature sawtimber size class)
		(3)	(40 to 70 percent crown coverage)

The primary disturbance initiating secondary forest succession was a stand-replacing wildfire. Additional disturbance by clearcut logging that predated the fire resulted in disturbance treatments of vegetation as follows:

No. of study areas	Disturbance treatment
13	Wildfire in standing timber
2	Wildfire in clearcut
3	Wildfire in shrubfield

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APPENDIX: VEGETATION INITIATING SECONDARY FOREST SUCCESSION ON SUNDANCE BURN STUDY AREAS— FLORISTIC COMPOSITION OF THE FIRST POSTFIRE YEAR AND SPECIES RESPONSE TO THE FIRE

Species	Abbreviation	Sundance Burn study area																	
		01	02	03	04	05	06	07	08	09	10	14	15	16	17	18	19	20	21
TREES																			
Abies grandis[1]	ABGR																		
Betula papyrifera	BEPA	RS[2]	RS			S				S						RS		S	
Larix occidentalis[1]	LAOC																		
Picea engelmannii[1]	PIEN																		
Pinus contorta	PICO	S														S	S	S	
Pinus monticola	PIMO	S	S																
Populus tremuloides	POTRE			R		RS			S	S	S						S	S	
Populus trichocarpa	POTRI			R															
Pseudotsuga menziesii	PSME				PS	P	PS	PS	P	P	P			P					
SHRUBS																			
Acer glabrum	ACGL	R	R	R		R							R	R	R	R		R	
Alnus sinuata	ALSI	R	R			R											R		
Amelanchier alnifolia	AMAL	R		R								R	R		R	R	R		R
Ceanothus sanguineus	CESA	S	S	S	S	S	S				S	S	RS	RS	RS	R*S			RS
Ceanothus velutinus	CEVE	S												RS	RS	RS			
Holodiscus discolor	HODI	R		R									R		R	RS			
Lonicera utahensis	LOUT				R					R			R		R	R	R		
Oplopanax horridum	OPHO									R									
Pachistima myrsinites	PAMY	RS		RS	RS	RS		S		S	RS	R	RS	RS	RS	RS	R	R	R
Prunus emarginata	PREM												R		R	R			R
Ribes lacustre	RILA																S		
Ribes viscosissimum	RIVI																S		
Rosa gymnocarpa	ROGY			R	R	R						R	R	R	R	R		R	R
Rubus leucodermis	RULE					S		RS	RS	RS	RS								
Rubus parviflorus	RUPA		R	R	R	R		RS	R	R	R			R		RS	R	R	R
Salix scouleriana	SASC	RS	RS	RS	S	RS	S	S	S	S	RS	RS	RS	RS	R	RS	RS	RS	RS
Sambucus racemosa	SARA							RS	RS	S	S								
Sorbus scopulina	SOSC	R				R							R						
Spiraea betulifolia	SPBE	R*											R	R	R	R*		R*	
Symphoricarpos albus	SYAL												R	R	R	R*			
Vaccinium membranaceum	VAME	R		R	R	R	R	R	R	R	R				R	R			R
HERBS (includes low woody plants)																			
Achillea millefolium	ACMI														R	R			
Adenocaulon bicolor	ADBI					R			R*	R*									
Agrostis alba	AGAL	S*												S*		S*			
Agrostis scabra	AGSC	S*														S*			
Anaphalis margaritacea	ANMA		X		X				X*	X	X*	X	X	X		X		X*	X*
Apocynum androsaemifolium	APAN	R*	R*	R*	R	R				R			R	R		R	R		R
Arabis holboellii	ARHO														S	S			
Aralia nudicaulis	ARNU		R																
Arnica cordifolia	ARCO												R		R				
Arnica latifolia	ARLA									R								R	
Asarum caudatum	ASCA									S									
Aster conspicuus	ASCO														R*				
Aster engelmannii	ASEN														R*	R*			
Athyrium filix-femina	ATFI							N		N									
Berberis repens	BERE												R	R	R	R			R
Calamagrostis rubescens	CARU	R*		R*									R*		R*	R*			R*
Calochortus apiculatus	CAAP														R*				
Carex deweyana[1]	CADE																		
Carex geyeri	CAGE														R				
Carex rossii	CARO	S		S	S	S		S		S	S	S	S	S	S	S			S
Castilleja miniata[1]	CAMI																		
Chenopodium album	CHAL					S*													
Cirsium arvense	CIAR							R*	R*										
Cirsium vulgare	CIVU							S					S	S		S			
Clintonia uniflora	CLUN	R		R	R	R	R	R	R	R		R			R			R	R
Collinsia parviflora	COPA												S*		S*	S*			

(con.)

PPENDIX: (Con.)

Species	Abbreviation	01	02	03	04	05	06	07	08	09	10	14	15	16	17	18	19	20	21
		Sundance Burn study area																	
onzya canadensis	COCA	S*	S*	S*	S*	S*			S*	S*	S*	S*		S*	S*	S*	S*	S*	S*
yptantha affinis	CRAF														S*	S*			
actylis glomerata	DAGL									S				S		S			
isporum hookeri	DIHO	R	R*	R	R	R*		R*	R*	R*		R		R	R	R*		R*	R*
racocephalum parviflorum	DRPA														S	S			
pilobium angustifolium	EPAN	S*	S*	S*	S*	S*	S*	R*S	S*	S*	S*	S*	S*	S*	S	S*	S*	S*	S
pilobium paniculatum	EPPA	S*		S*	S*						S*	S	S	S		S*	S*		
pilobium watsonii	EPWA	S*	S*	S*	S*		S	S	S*	S*	S*	S	S	S	S	S*	S*	S*	
quisetum arvense	EOAR								R										
rigeron acris[1]	ERAC																		
rucastrum gallicum	ERGA					S*													
estuca arundinacea	FEAR	S	S	S*	S	S	S	S	S	S	S	S							
ilago arvensis	FIAR	S*							S*					S*			S*		
ragaria vesca	FRVE														X	X			
alium triflorum	GATR								X		X								
eranium bicknellii	GEBI												S	S			S		S
naphalium microcephalum	GNMI	S	S		S	S		S	S*	S	S	S	S	S	S	S	S	S	S*
naphalium palustre	GNPA		S*							S*			S*	S*	S*			S*	
abenaria elegans	HAEL	R*											R*		R*	R*			R*
ieracium albiflorum	HIAL										S								
liamna rivularis	ILRI			S	S	S					S	R*	S	R*	S	S	S	S	S
actuca serriola	LASE							S*	S*	S*		S	S			S*			
ilium columbianum	LIOC	R*		R*	R*	R*									R	R*		R	R*
olium multiflorum	LOMU									S*									
upinus argenteus	LUAR												R		R	R*			
Luzula piperi	LUPI										X*								
Phleum pratense	PHPR									S*				S		S*			
Plantago major	PLMA										X*								
Poa palustris	POPA					S*													
Polygonum douglasii	PODO										S*		S		S*				
Polygonum lapathifolium	POLA										S*								
Pteridium aquilinum	PTAO	R	R	R	R	R		R	R	R	R	R		R		R	R	R	R
Pyrola picta	PYPI																R		
Pyrola secunda	PYSE									R									
Rumex acetosella	RUAC	R																	
Secale cereale	SECE					S*	S*	S*		S*	S*	S*			S*	S*	S*		
Senecio vulgaris	SEVU				S*	S*	S*	S*	S*	S*	S*			S*					
Silene noctiflora	SINO					S*													
Smilacina racemosa	SMRA															R*			
Smilacina stellata	SMST					R		R					R			R*			R
Solidago canadensis	SOCA														R	R*			R
Spergularia rubra	SPRU						S*		S*		S*						S*	S*	
Stellaria media	STME					S*					S*					S*			
Stellaria obtusa	STOB										S								
Taraxacum officinale	TAOF	S							S		S								
Thalictrum occidentale	THOC					R									R	R			
Tiarella trifoliata var. *unifoliata*	TITRU								R	R									
Trautvetteria caroliniensis	TRCA								R	R									
Trifolium repens	TRRE		S*			S*	S*		S	S*	S*					S*			S
Trillium ovatum	TROV							R		R									
Viola glabella	VIGL							R*S	R*	R									
Viola orbiculata	VIOR	R			R			R*	R*		R			S		R			R
Xerophyllum tenax	XETE	R					N			N			N		R	R	R		

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[1] Not observed in initial flora

[2] Key to appendix symbols
N Nonsurvivor
P Reforestation transplant.
R Survivor, regrowing from burned plant.
S Colonizer, seedling first postfire year.
X Present first year; postfire origin unascertained
* Flowering first postfire year.

INDEX TO DATA BASE TABLES FOR SUNDANCE BURN STUDY AREAS

Tabulated data are presented in order of increasing SD study area number. Study areas are indexed below by prefire vegetation and exposure of slope.

Exposure	Study area No.	Table No.	Page
Wildfire in standing timber			
North	SD-06	6-1 - 6-6	44
	SD-09	9-1 - 9-6	62
	SD-20	17-1 - 17-6	110
East	SD-01	1-1 - 1-6	14
	SD-02	2-1 - 2-6	20
	SD-03	3-1 - 3-6	26
	SD-05	5-1 - 5-6	38
	SD-19	16-1 - 16-6	104
South	SD-04	4-1 - 4-6	32
	SD-10	10-1 - 10-6	68
West	SD-14	11-1 - 11-6	74
	SD-15	12-1 - 12-6	80
	SD-16	13-1 - 13-6	86
Wildfire on clearcut area			
North	SD-08	8-1 - 8-6	56
East	SD-07	7-1 - 7-6	50
Wildfire in shrubfield			
South	SD-21	18-1 - 18-6	116
West	SD-17	14-1 - 14-6	92
	SD-18	15-1 - 15-6	98

SUNDANCE BURN: 1802-16 Study Area SD-01

Site location and description: NW¼SW¼ sec. 9, T. 60 N., R. 2 W., BM; Elevation: 2,950 ft; Exposure: East (Az. 10
Slope: 20%

Forest cover type and tree size class: Western larch seedling and sapling, 40 to 70% canopy coverage

Reconstructed prefire forest stand:
Tree component: Conifer density: 11.6/0.01 ha; Average d.b.h.: 15.2 cm; Basal area: 4,298 cm^2/0.01 ha
Shrub component: ALSI 50%; SASC 50% (Shrub density: 0.8/0.01 ha);
Other species present: ACGL, AMAL, HODI, PAMY, SOSC, SPBE, VAME

Disturbance treatment:
Wildfire: September 1, 1967 (1900-1930 hrs); Succession year 1:1968;
Fire intensity: 3,400 to 22,500 Btu/sec/ft; Rate of spread: 1 to 6 mi/h;
Fire severity: R-N index: 5-M; Overstory crown foliage: Consumed; Litter-duff: Consumed

Table 1-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 1-1

Life form component	Succession year													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Tree	--	--	--	1	--	1	2	3	4	8	10	17	19	19
Shrub	2	4	4	12	14	17	21	18	29	29	39	49	77	68
Herb	14	37	31	33	32	32	28	34	38	36	34	46	25	34
Total veg.	16	41	35	46	45	49	51	55	70	73	82	112	121	121

Table 1-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 1-2

Life form component	Succession year													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Tree	--	--	--	0.1	--	0.2	0.9	1.7	6.2	16.2	24.8	52.9	60.5	82.7
Shrub	0.9	1.8	2.1	3.8	7.5	8.1	8.7	9.3	24.9	27.6	31.2	47.4	94.3	110.4
Herb	3.7	10.2	7.4	8.6	8.6	8.6	7.6	9.6	11.7	11.2	10.0	16.0	8.0	13.6
Total veg.	4.6	12.0	9.6	12.5	16.1	16.8	17.2	20.6	42.8	55.0	65.9	116.4	162.8	206.8

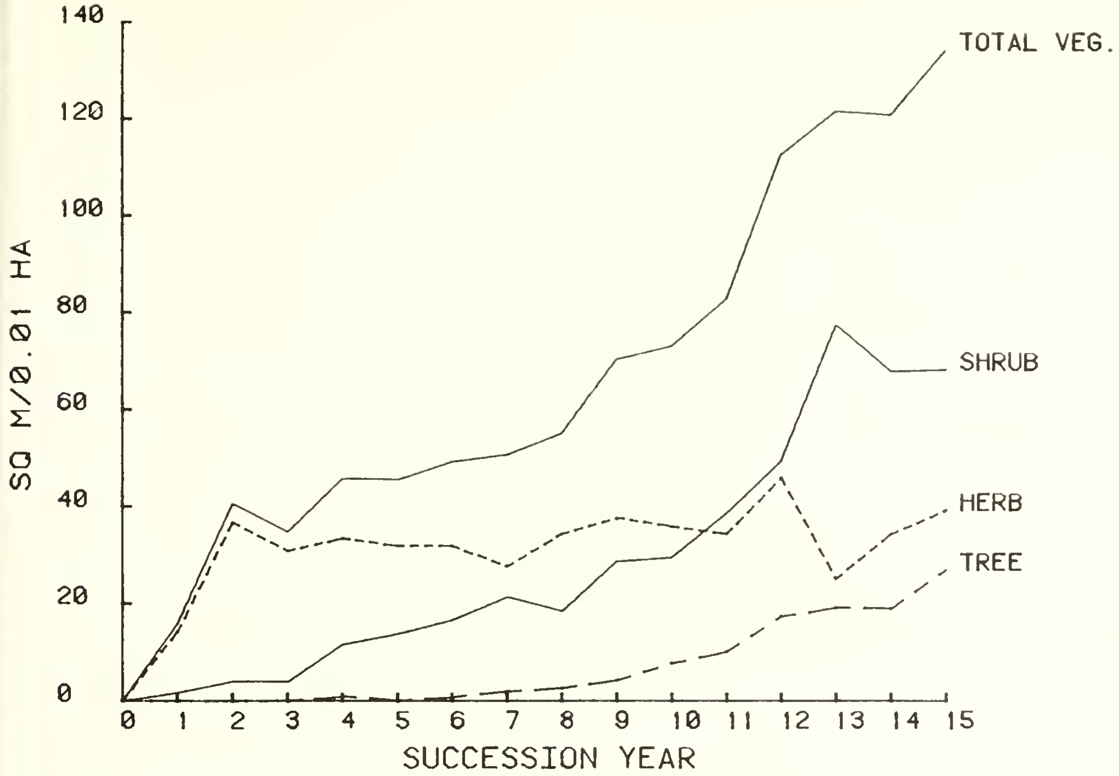


Figure 1-1.—Vegetative cover.

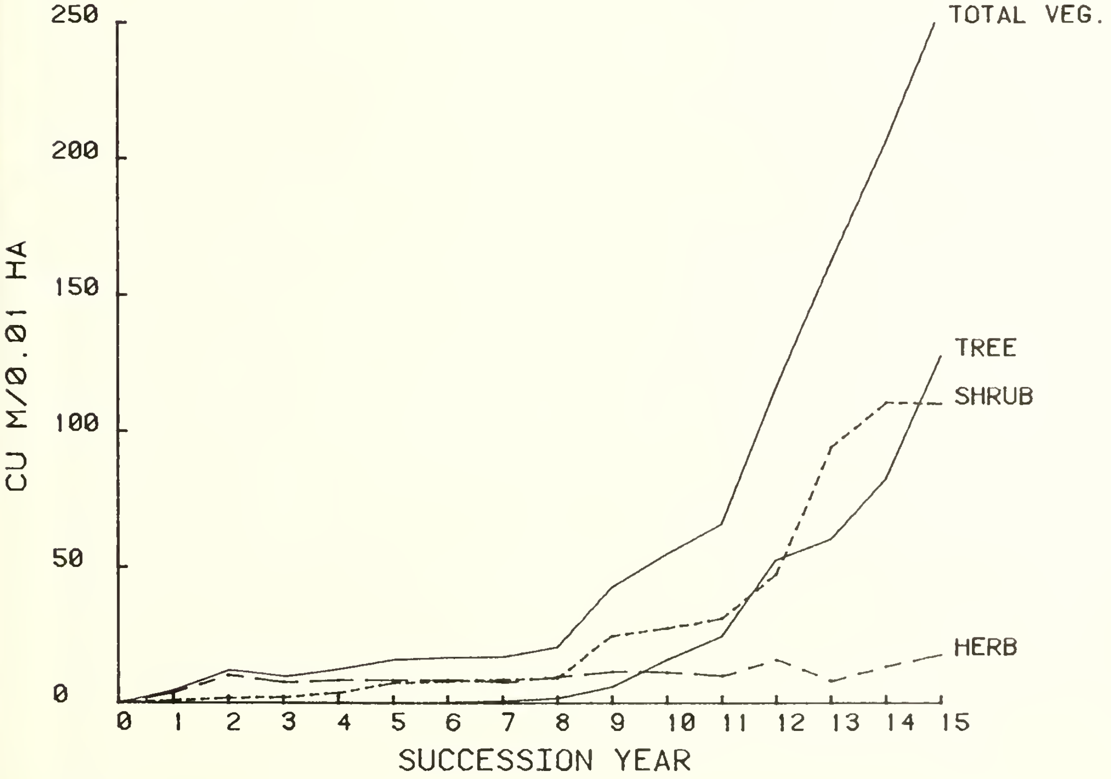


Figure 1-2.—Vegetative volume.

Table 1-3.--Cover development of tree and shrub components (m^2/0.01 ha or %), fig. 1-3

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tree															
ABGR	--	--	--	1	--	1	2	2	2	3	3	4	4	4	4
BEPA	--	--	--	--	--	--	--	--	--	--	--	--	<1	<1	1
PICO	--	--	--	--	--	--	<1	1	2	5	7	13	14	14	22
POTRE	--	--	--	--	--	--	--	--	--	--	--	--	<1	<1	<1
Shrub															
ALSI	--	--	--	--	--	--	--	--	--	--	--	2	4	4	5
CESA	--	--	--	--	--	--	--	--	2	1	1	2	2	9	10
CEVE	--	--	--	1	3	2	2	2	7	13	15	24	39	32	32
PAMY	--	--	--	2	2	1	1	1	1	1	2	2	2	3	3
SASC	1	2	3	3	3	5	9	6	10	7	9	8	17	12	9
SPBE	--	--	--	--	--	--	--	--	--	--	1	1	2	1	2
VAME	1	2	1	6	6	9	10	9	9	8	11	10	12	6	7

Table 1-4.--Cover development of herb component (m^2/0.01 ha or %), fig. 1-4

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
APAN	--	--	--	--	--	--	--	--	--	--	1	--	--	--	2
CARO	--	1	1	--	--	--	--	--	--	--	--	--	--	--	--
CLUN	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2
EPAN	--	3	3	3	2	--	1	1	--	--	--	1	--	1	1
PTAQ	9	22	12	16	12	18	18	18	28	18	22	35	18	23	25
XETE	1	1	5	7	8	8	6	11	7	7	9	8	6	10	9
Misc.	4	9	9	8	9	6	3	4	3	12	2	2	2	--	--

SD - 01

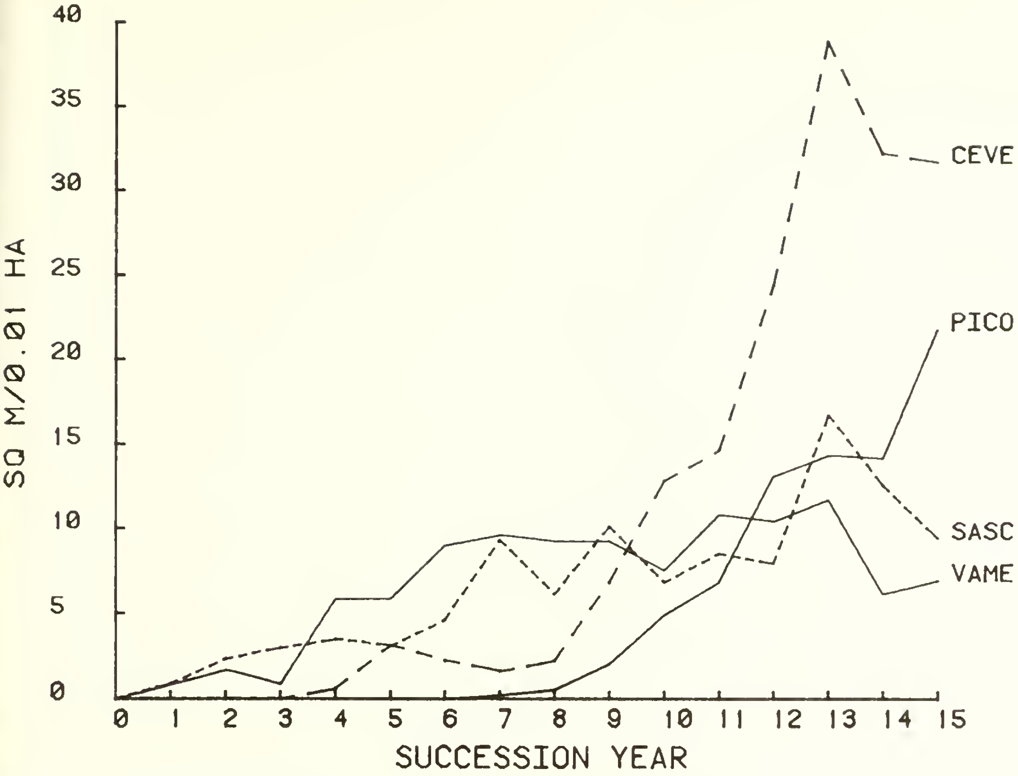


Figure 1-3.—Tree and shrub cover.

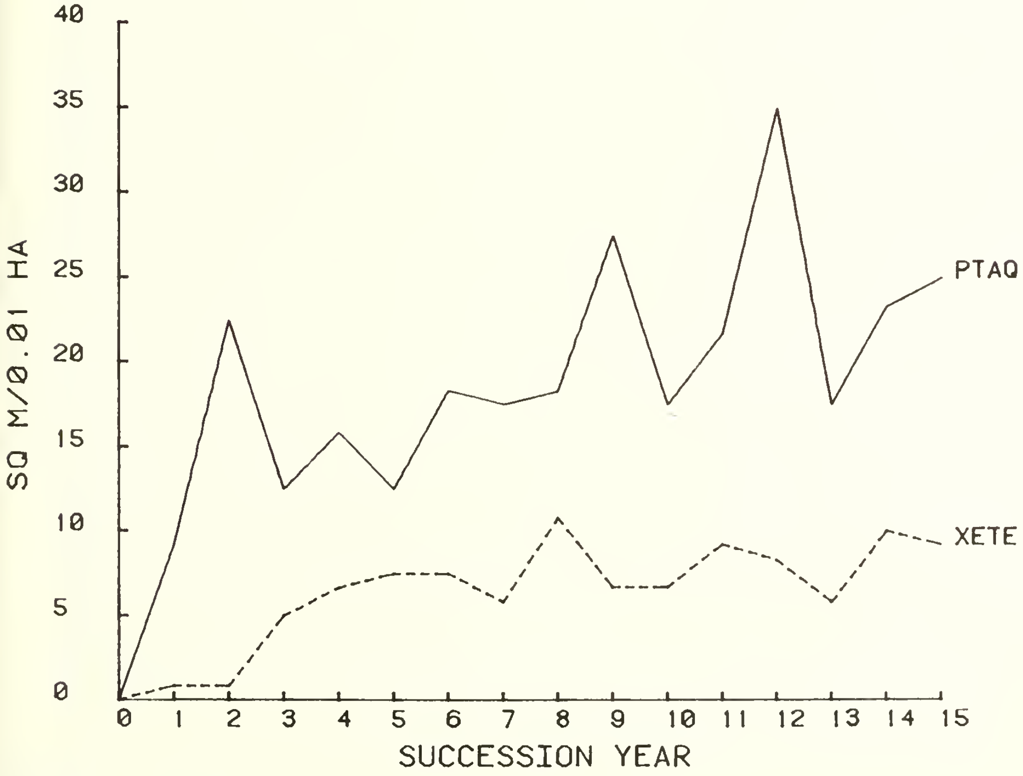


Figure 1-4.—Herb cover.

Table 1-5.--Volume development of tree and shrub components (m^3/0.01 ha), fig. 1-5

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tree															
ABGR	--	--	--	0.1	--	0.2	0.5	0.8	0.9	1.4	1.8	2.6	3.9	5.0	6.0
BEPA	--	--	--	--	--	--	--	--	--	--	--	--	.3	1.2	2.2
PICO	--	--	--	--	--	--	.4	.9	5.3	14.8	23.0	50.4	56.0	76.1	118.9
POTRE	--	--	--	--	--	--	--	--	--	--	--	--	.3	.5	.6
Shrub															
ALSI	--	--	--	--	--	--	--	--	--	--	--	3.1	7.3	9.6	9.0
CESA	--	--	--	--	--	--	--	--	4.6	3.5	3.3	5.5	6.8	24.3	30.2
CEVE	--	--	--	.4	2.5	1.8	1.1	2.2	8.2	15.4	16.1	29.3	57.8	60.6	57.9
PAMY	--	--	--	.2	0.2	.1	.1	.1	.1	.1	.4	.2	.4	.5	.6
SASC	0.8	1.6	2.0	2.3	3.7	4.6	5.6	5.1	10.1	7.1	9.4	7.3	18.8	13.8	10.1
SPBE	--	--	--	--	--	--	--	--	--	--	.1	.2	.4	.1	.5
VAME	.1	.2	.1	1.0	1.1	1.6	2.0	1.9	1.9	1.4	1.9	1.8	2.7	1.4	1.7

Table 1-6.--Volume development of herb component (m^3/0.01 ha), fig. 1-6

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
APAN	--	--	--	--	--	--	--	--	--	--	0.1	--	--	--	0.3
CARO	--	0.1	<0.1	--	--	--	--	--	--	--	--	--	--	--	--
CLUN	--	--	--	--	--	--	--	--	--	--	--	--	--	--	.2
EPAN	--	1.0	.8	1.0	0.8	--	0.3	0.3	--	--	--	0.8	--	0.4	.3
PTAQ	2.9	7.5	4.0	5.1	4.4	6.0	5.7	6.4	9.8	6.7	7.3	12.7	6.3	10.3	11.5
XETE	.1	.2	1.0	1.2	1.5	1.4	1.1	2.0	1.4	1.7	2.2	2.3	1.4	3.0	5.6
Misc.	.7	1.5	1.6	1.4	1.8	1.2	.5	.8	.4	2.9	.4	.2	.2	--	--

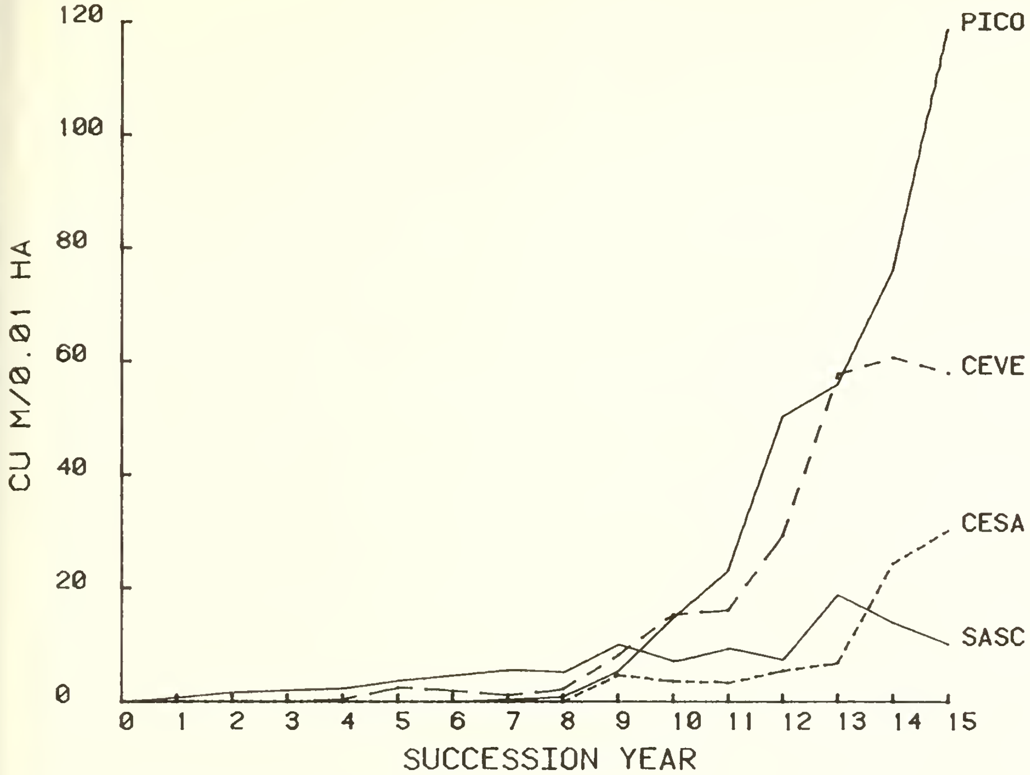


Figure 1-5.—Tree and shrub volume.

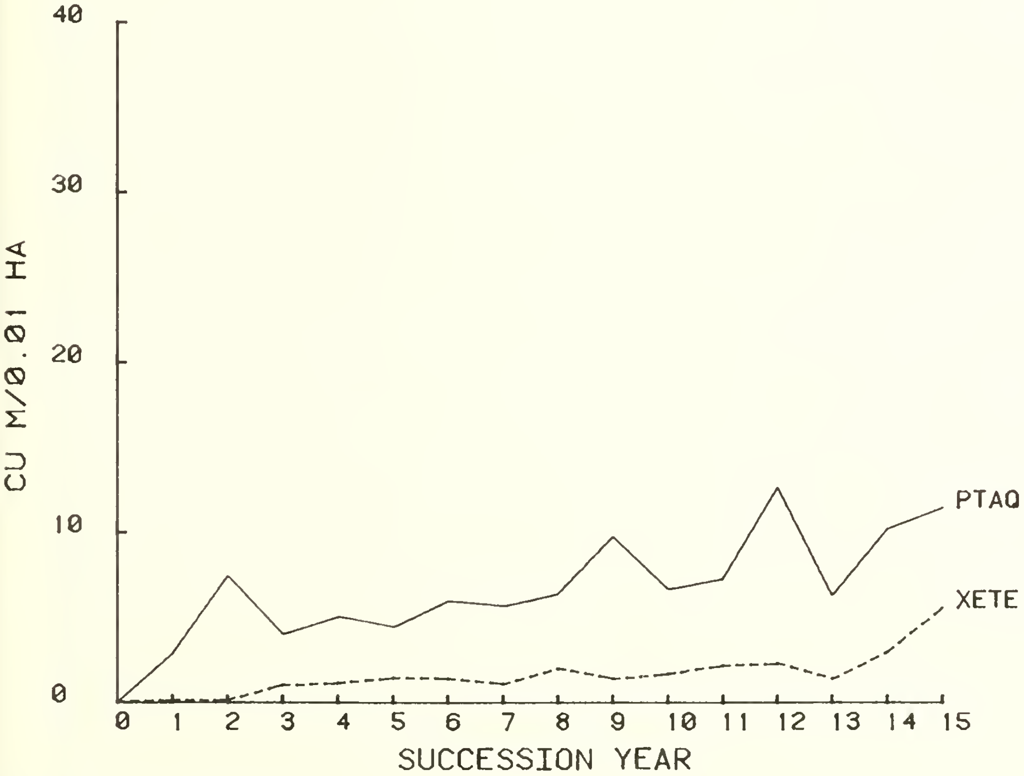


Figure 1-6.—Herb volume.

SUNDANCE BURN: 1802-16 Study Area SD-02

Site location and description: SE¼SE¼ sec. 8, T. 60 N., R. 2 W., BM; Elevation: 3,300 ft; Exposure: East (Az. 90;
Slope: 20%

Forest cover type and tree size class: Western larch immature poletimber, 40 to 70% canopy coverage

Reconstructed prefire forest stand:
Tree component: Conifer-paper birch density: 14.8/0.01 ha; Average d.b.h.: 11.4 cm;
Basal area: 2,144 cm^2/0.01 ha
Shrub component: SASC 100% (Shrub density: 0.4/0.01 ha);
Other species present: ACGL, ALSI, RUPA

Disturbance treatment:
Wildfire: September 1, 1967 (1800-1900 hrs); Succession year 1:1968;
Fire intensity: 3,400 to 11,300 Btu/sec/ft; Rate of spread: 1 to 2.5 mi/h;
Fire severity: R-N index: 5-M; Overstory crown foliage: Mostly consumed or scorch killed; Litter-duff: Consumed

Table 2-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 2-1

Life form component	Succession year											
	1	2	3	4	5	6	7	8	9	10	11	12
Tree	--	--	--	--	--	1	3	1	45	54	53	76
Shrub	11	19	24	29	37	52	64	84	57	63	82	76
Herb	83	78	75	72	72	69	72	78	77	78	88	86
Total veg.	94	98	99	100	110	122	139	162	179	194	223	238

Table 2-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 2-2

Life form component	Succession year											
	1	2	3	4	5	6	7	8	9	10	11	12
Tree	--	--	--	--	--	0.3	1.2	0.2	183.3	230.7	283.4	409.9
hrub	5.1	12.3	11.7	17.1	29.6	64.2	71.5	119.5	84.2	111.3	163.2	145.9
erb	35.4	45.8	47.5	44.0	41.0	42.8	40.5	48.6	45.4	59.4	79.2	81.7
otal veg.	40.5	58.1	59.2	61.1	70.6	107.2	113.2	168.4	312.9	401.4	525.9	637.5

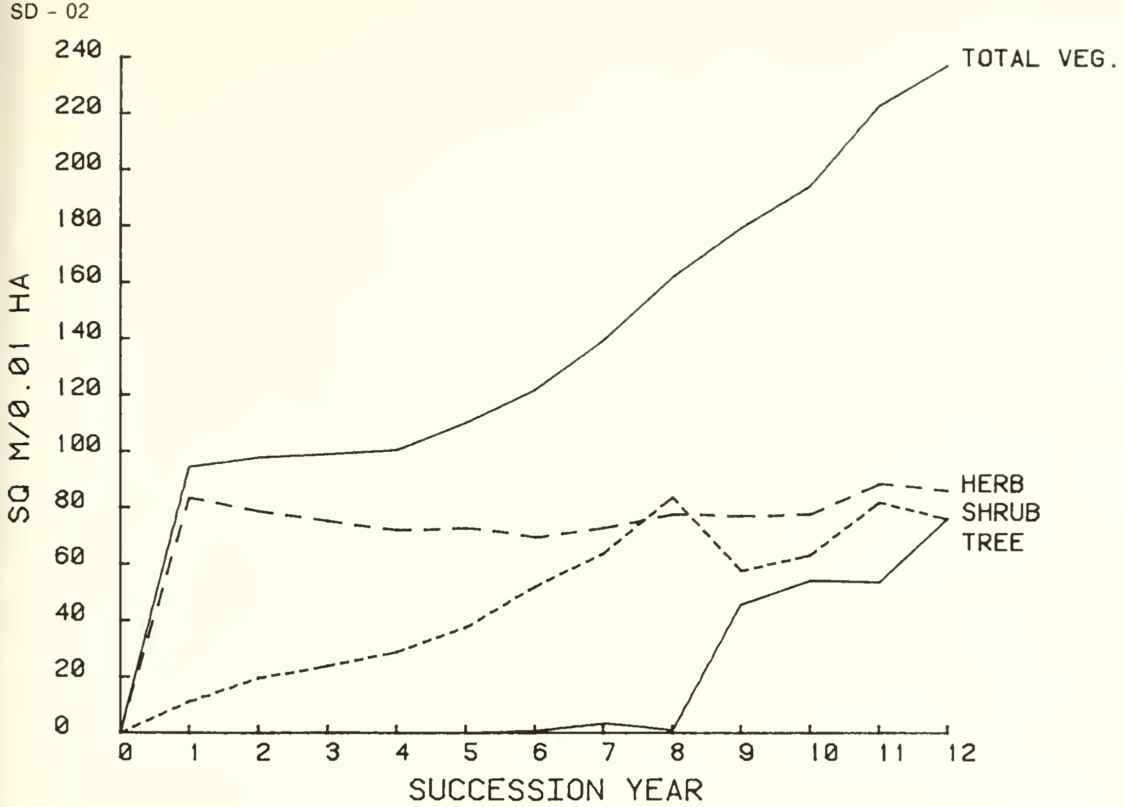


Figure 2-1.—Vegetative cover.

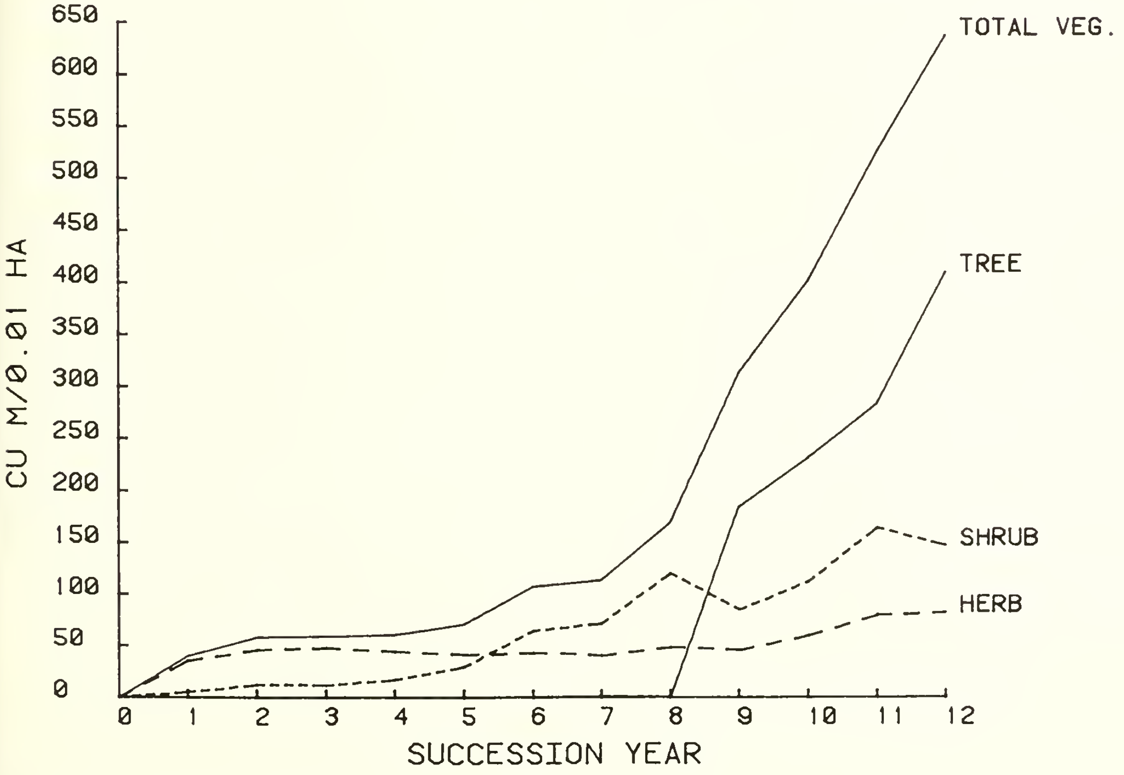


Figure 2-2.—Vegetative volume.

Table 2-3.--Cover development of tree and shrub components (m^2/0.01 ha or %), fig. 2-3

Species	Succession year 1	2	3	4	5	6	7	8	9	10	11	12
Tree												
BEPA	--	--	--	--	--	1	3	1	43	48	47	69
PSME	--	--	--	--	--	--	--	--	2	5	6	7
Shrub												
ALSI	--	<1	<1	1	1	2	--	2	--	--	2	<1
CESA	--	<1	1	3	11	20	33	43	23	32	49	35
CEVE	--	--	--	--	--	--	--	--	--	--	--	<1
PAMY	--	--	--	--	--	--	--	--	--	--	--	1
RUPA	10	12	14	17	15	13	15	18	18	15	11	14
SASC	1	7	8	8	10	16	15	20	16	16	20	25

Table 2-4.--Cover development of herb component (m^2/0.01 ha or %), fig. 2-4

Species	Succession year 1	2	3	4	5	6	7	8	9	10	11	12
ANMA	--	--	--	--	2	--	--	2	1	1	1	1
APAN	2	6	6	2	6	7	5	3	5	10	4	5
ARNU	--	--	--	--	--	--	--	--	1	--	--	--
DIHO	--	--	--	--	--	--	--	--	--	2	--	1
EPAN	40	30	22	27	22	23	8	14	12	9	8	5
HIAL	--	--	--	--	--	--	--	--	--	1	--	--
PTAQ	40	42	43	37	33	38	59	57	57	55	76	74
TRRE	--	--	--	--	5	--	--	--	--	--	--	--
Misc.	2	2	3	5	4	1	--	2	1	--	--	--

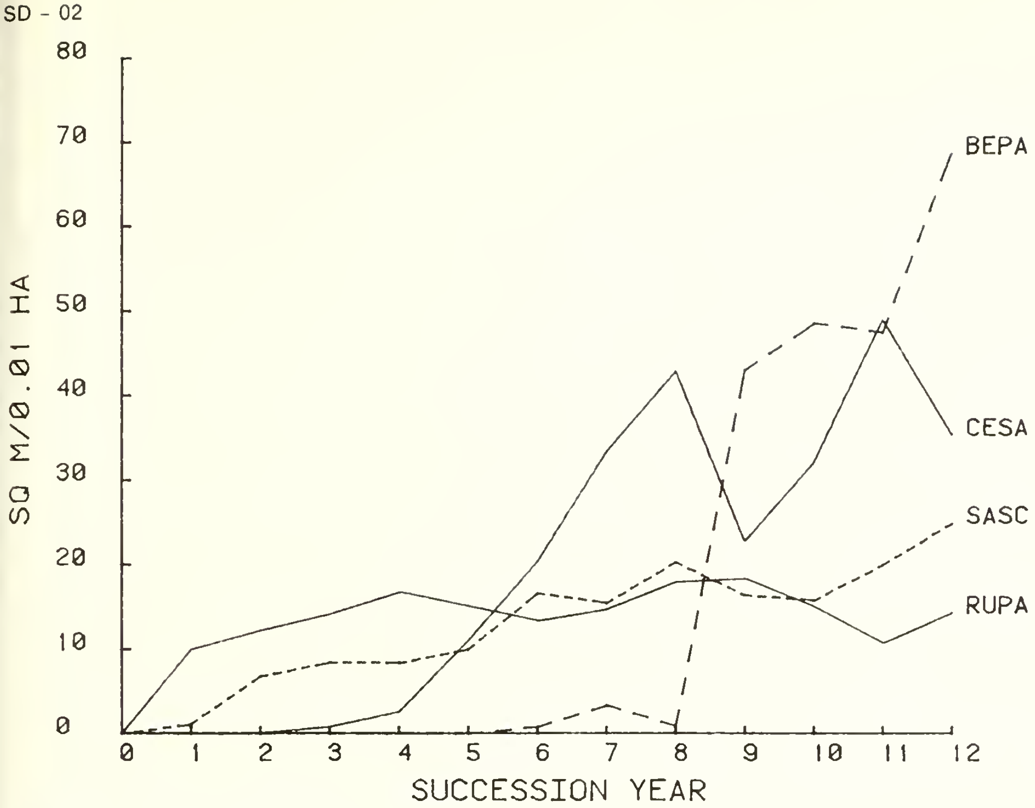


Figure 2-3.—Tree and shrub cover.

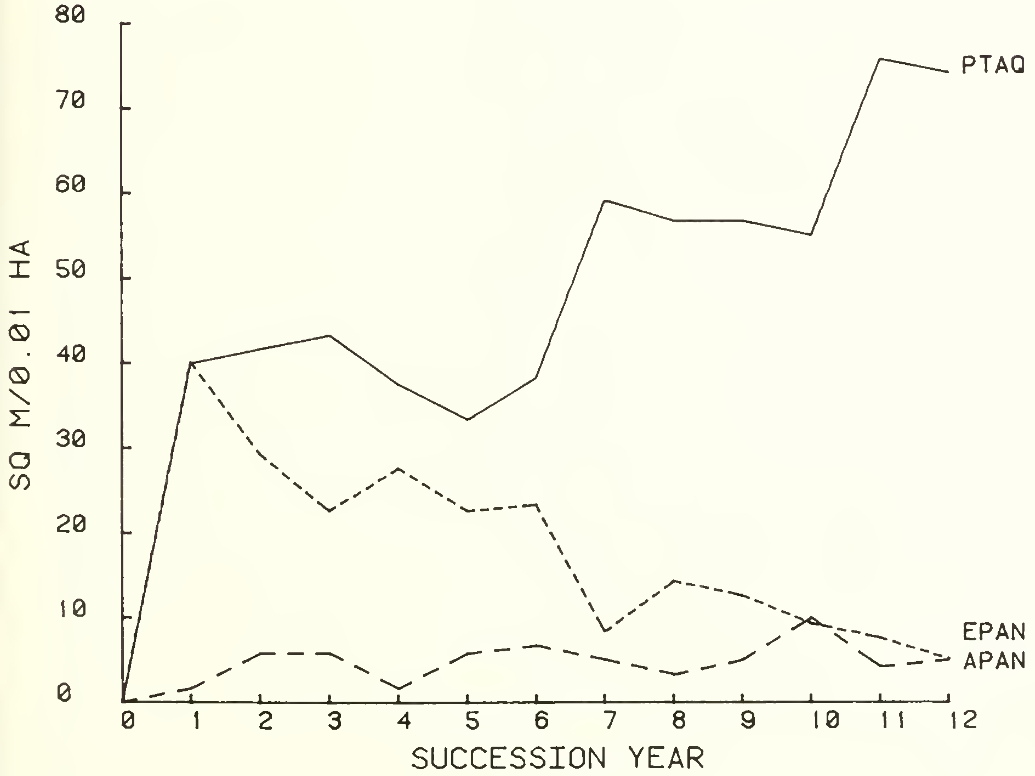


Figure 2-4.—Herb cover.

Table 2-5.--Volume development of tree and shrub components (m^3/0.01 ha), fig. 2-5

	Succession year											
Species	1	2	3	4	5	6	7	8	9	10	11	12
Tree												
BEPA	--	--	--	--	--	0.3	1.2	0.2	179.1	219.6	268.4	386.4
PSME	--	--	--	--	--	--	--	--	4.1	11.1	15.0	23.5
Shrub												
ALSI	--	0.8	1.1	3.5	4.2	4.8	--	5.1	--	--	6.1	<0.1
CESA	--	<.1	.5	2.4	13.5	40.2	52.9	81.0	51.7	79.8	112.6	96.0
CEVE	--	--	--	--	--	--	--	--	--	--	--	.1
PAMY	--	--	--	--	--	--	--	--	--	--	--	.5
RUPA	3.2	3.5	4.2	4.3	3.9	3.3	4.2	6.9	8.9	4.5	4.0	5.1
SASC	1.9	7.9	5.9	6.9	8.0	15.8	14.4	26.4	23.6	26.9	40.5	44.1

Table 2-6.--Volume development of herb component (m^3/0.01 ha), fig. 2-6

	Succession year											
Species	1	2	3	4	5	6	7	8	9	10	11	12
ANMA	--	--	--	--	0.8	--	--	0.8	0.3	0.8	0.5	0.8
APAN	0.3	2.0	2.2	0.5	2.0	2.6	1.3	1.1	1.6	3.5	1.6	1.5
ARNU	--	--	--	--	--	--	--	--	.1	--	--	--
DIHO	--	--	--	--	--	--	--	--	--	.4	--	.2
EPAN	17.7	18.6	13.2	14.3	13.9	17.1	3.9	7.0	6.2	6.0	5.4	3.8
HIAL	--	--	--	--	--	--	--	--	--	<.1	--	--
PTAQ	17.1	24.9	31.1	27.5	22.8	22.9	35.2	39.4	37.0	48.7	71.7	75.3
TRRE	--	--	--	--	.6	--	--	--	--	--	--	--
Misc.	.3	.4	.9	1.6	.9	.2	--	.4	.2	--	--	--

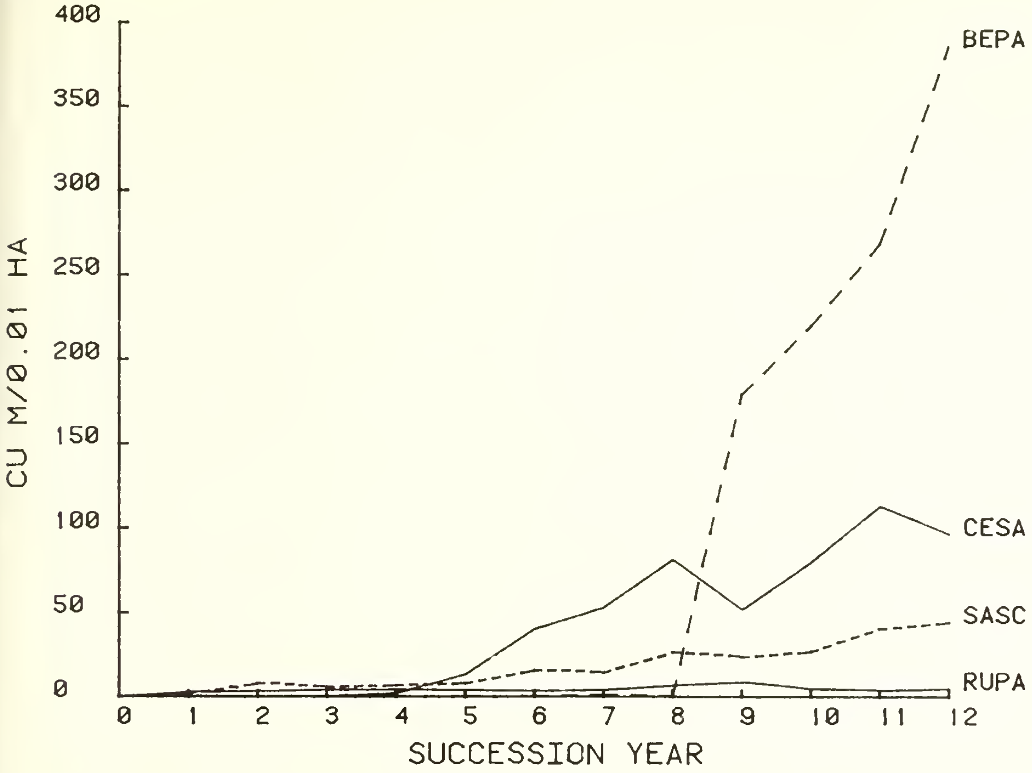


Figure 2-5.—Tree and shrub volume.

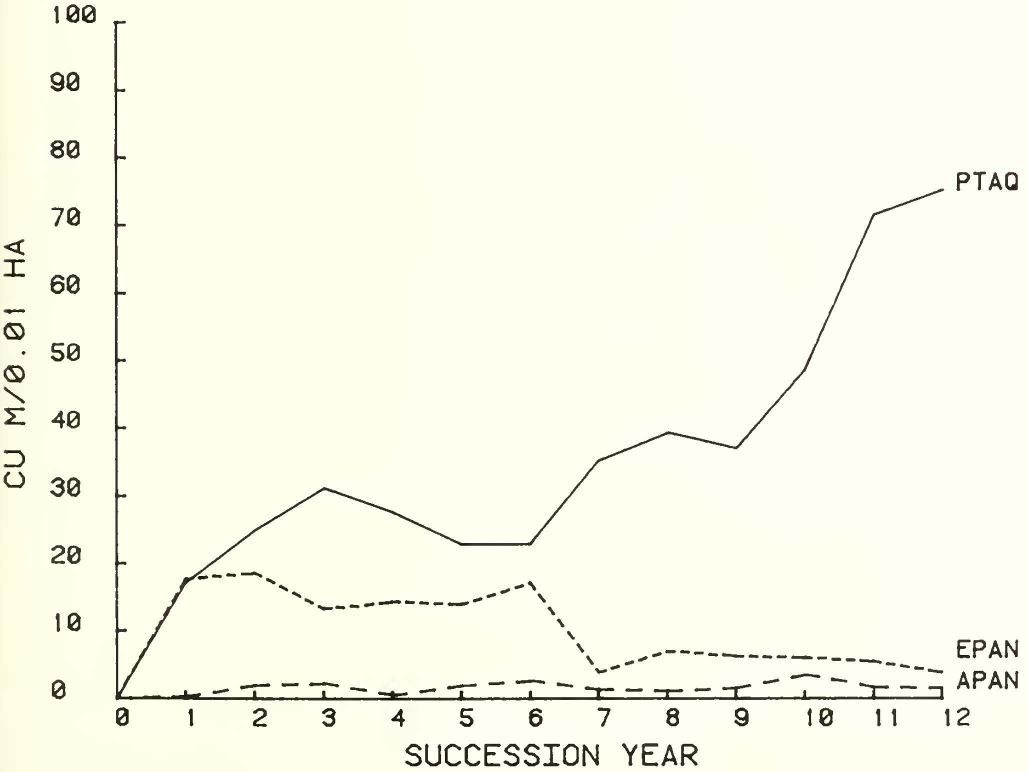


Figure 2-6.—Herb volume.

SUNDANCE BURN: 1802-16 Study Area SD-03

Site location and description: NW¼SE¼ sec. 8, T. 60 N., R. 2 W., BM; Elevation: 3,550 ft; Exposure: East (Az. 1
Slope: 35%

Forest cover type and tree size class: Western larch immature poletimber, 40 to 70% canopy coverage

Reconstructed prefire forest stand:
Tree component: Conifer density: 9.2/0.01 ha; Average d.b.h.: 20.1 cm; Basal area: 4,644 cm^2/0.01 ha
Shrub component: AMAL 17%, HODI 17%, POTRE 50% (Shrub density: 2.4/0.01 ha);
Other species present: ACGL, PAMY, ROGY, RUPA, SASC, VAME

Disturbance treatment:
Wildfire: September 1, 1967 (1800-1900 hrs); Succession year 1:1968;
Fire intensity: 3,400 to 11,300 Btu/sec/ft; Rate of spread: 1 to 2.5 mi/h;
Fire severity: R-N index: 5-M; Overstory crown foliage: Consumed; Litter: Consumed; Duff: Almostly complete
consumed

Table 3-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 3-1

Life form component	Succession year											
	1	2	3	4	5	6	7	8	9	10	11	12
Tree	4	--	--	--	--	--	--	--	7	6	3	7
Shrub	14	47	58	96	135	132	150	204	143	115	107	132
Herb	52	60	58	62	65	67	46	62	72	69	73	77
Total veg.	70	107	116	159	200	199	196	266	222	189	183	216

Table 3-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 3-2

Life form component	Succession year											
	1	2	3	4	5	6	7	8	9	10	11	12
Tree	2.7	--	--	--	--	--	--	--	14.1	16.3	9.8	23.5
Shrub	9.3	49.3	52.0	112.0	162.0	226.6	196.0	317.9	242.1	219.8	200.9	219.0
Herb	15.1	25.8	29.6	31.3	37.0	46.5	25.4	42.0	54.5	65.0	68.6	75.8
Total veg.	27.1	75.2	81.5	143.3	199.0	273.0	221.4	359.9	310.6	301.1	279.3	318.3

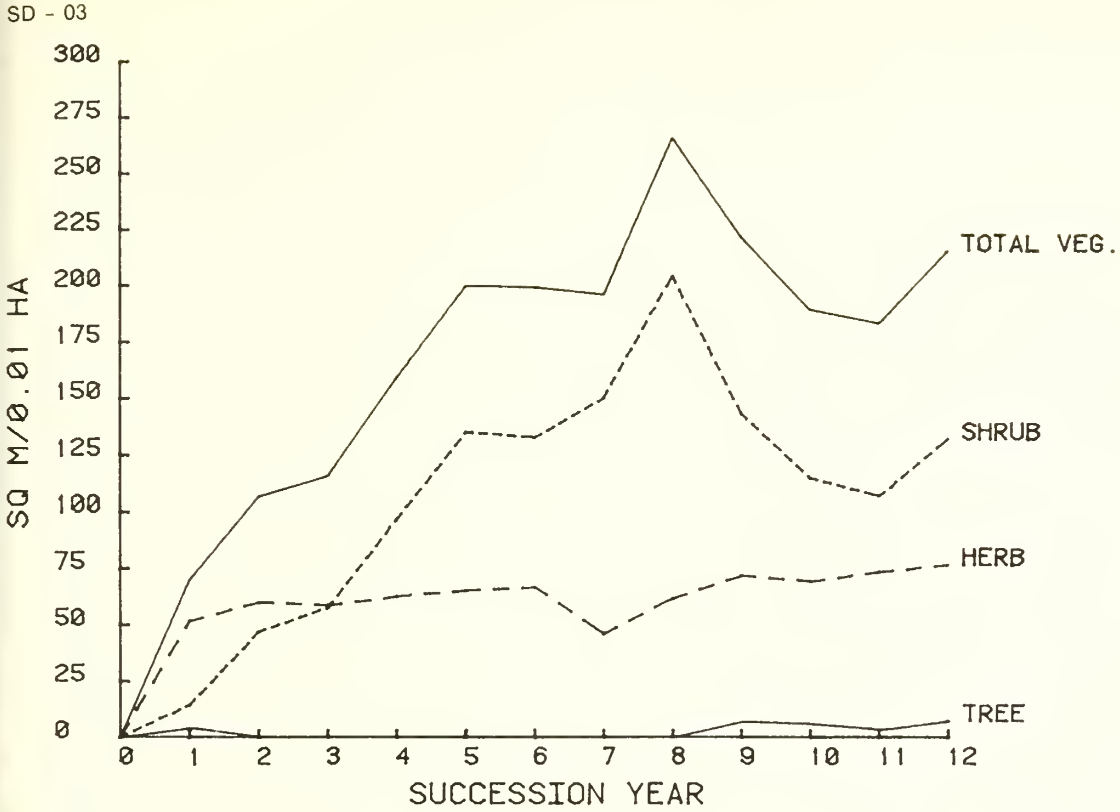


Figure 3-1.—Vegetative cover.

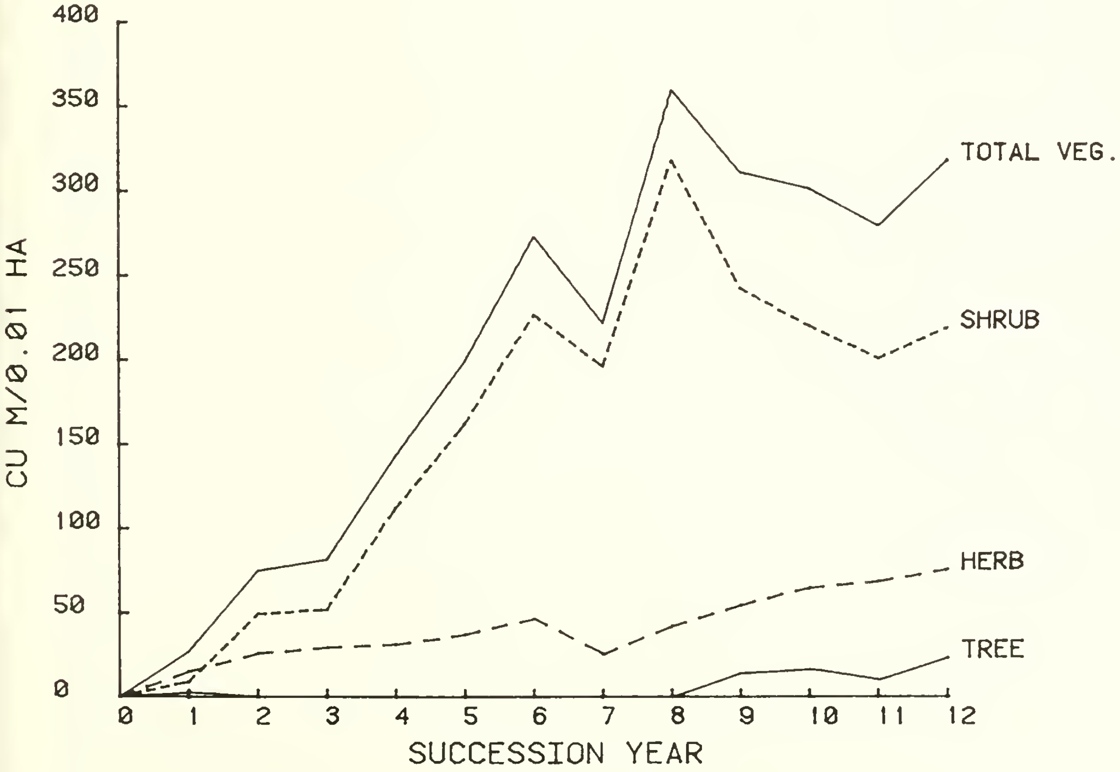


Figure 3-2.—Vegetative volume.

Table 3-3.--Cover development of tree and shrub components (m^2/0.01 ha or %), fig. 3-3

	Succession year											
Species	1	2	3	4	5	6	7	8	9	10	11	12
Tree												
POTRE	4	--	--	--	--	--	--	--	7	5	2	6
PSME	--	--	--	--	--	--	--	--	--	1	1	2
Shrub												
ACGL	--	--	--	--	--	1	--	1	--	--	1	--
AMAL	1	2	3	3	2	6	2	6	2	3	1	2
CESA	2	20	27	60	104	93	115	158	107	73	59	78
HODI	3	7	11	5	5	1	8	1	1	2	1	2
PAMY	1	1	2	5	5	8	8	9	8	15	18	20
PREM	--	--	--	--	--	--	--	--	<1	--	--	--
RIVI	--	--	--	--	--	1	--	--	--	--	--	--
ROGY	--	--	--	--	<1	<1	<1	2	1	<1	<1	1
RUPA	5	2	1	3	4	4	3	8	6	5	2	4
SASC	2	15	13	19	14	20	13	19	18	17	24	25

Table 3-4.--Cover development of herb component (m^2/0.01 ha or %), fig. 3-4

	Succession year											
Species	1	2	3	4	5	6	7	8	9	10	11	12
ANMA	--	--	--	--	--	--	--	--	1	1	--	--
APAN	2	1	1	4	7	5	4	8	8	14	12	8
ARNU	--	--	--	--	--	--	--	--	--	1	2	2
CARU	--	--	--	--	--	--	--	--	--	1	--	1
CARO	--	--	--	--	1	2	2	2	2	1	3	3
CAMI	--	--	--	--	--	--	--	--	--	--	1	1
DIHO	--	2	2	2	2	2	3	2	3	2	2	3
EPAN	32	25	27	24	23	15	6	5	7	3	6	1
FEAR	--	--	--	--	--	--	1	1	1	1	2	1
PTAQ	14	22	24	24	27	41	28	40	49	46	45	56
Misc.	3	10	5	8	5	2	2	2	1	--	1	--

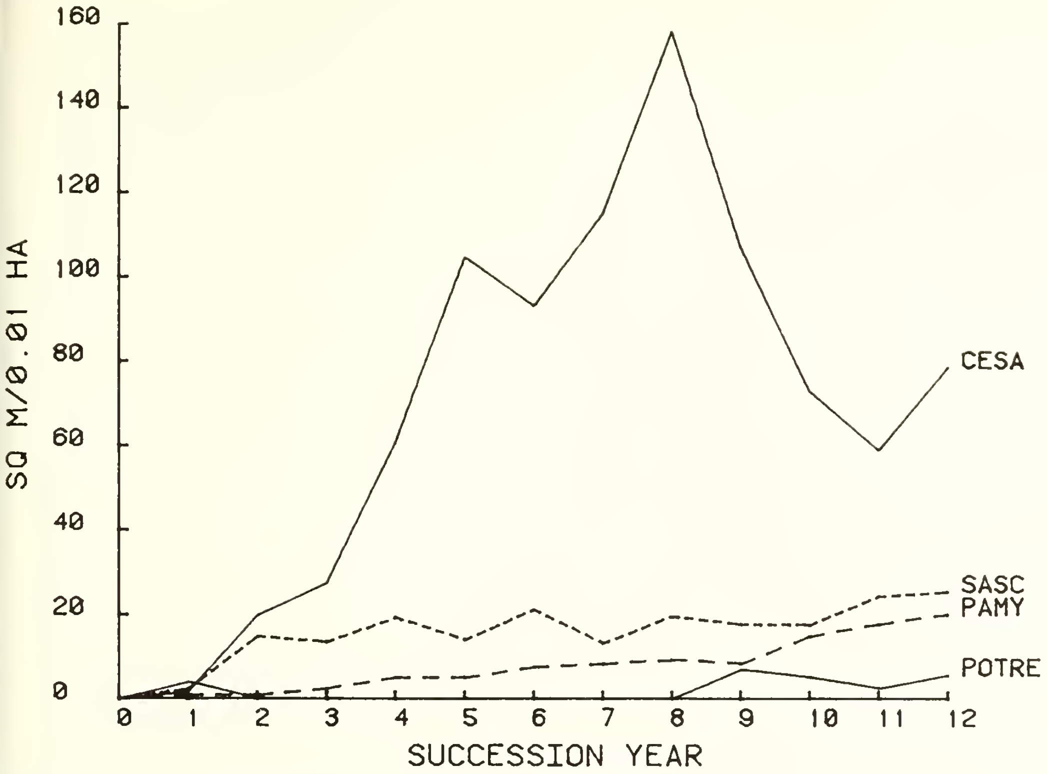


Figure 3-3.—Tree and shrub cover.

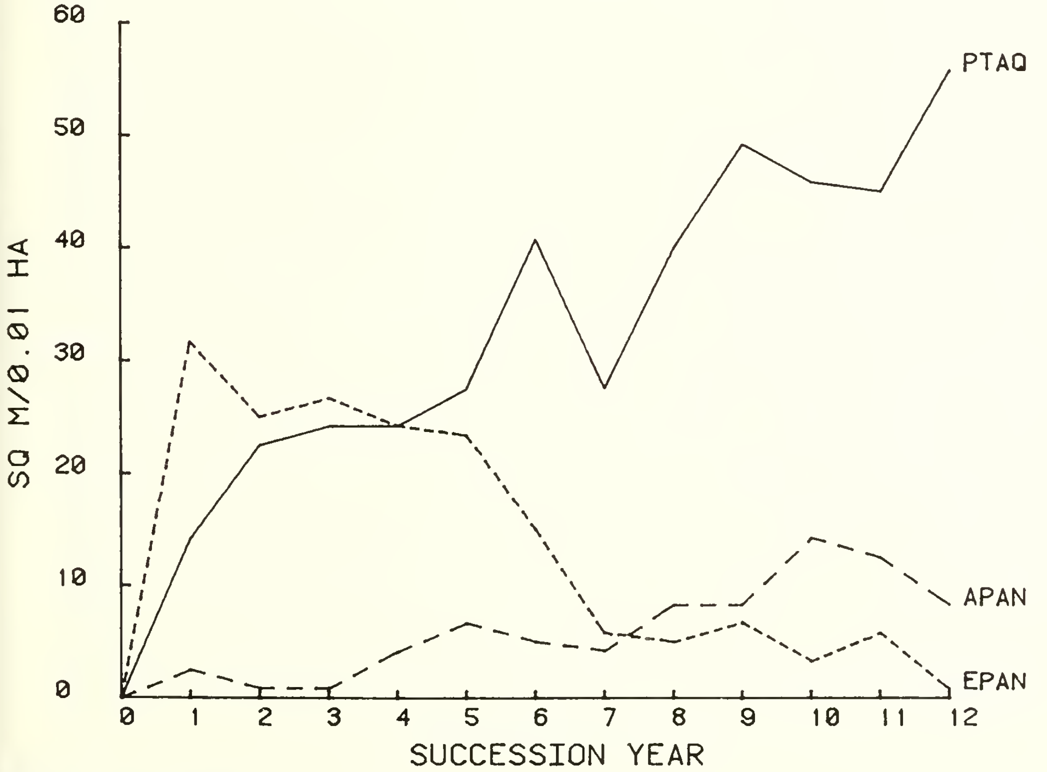


Figure 3-4.—Herb cover.

Table 3-5.--Volume development of tree and shrub components (m³/0.01 ha), fig. 3-5

Species	Succession year											
	1	2	3	4	5	6	7	8	9	10	11	12
Tree												
POTRE	2.7	--	--	--	--	--	--	--	14.1	15.1	8.4	20.0
PSME	--	--	--	--	--	--	--	--	--	1.1	1.4	3.5
Shrub												
ACGL	--	--	--	--	--	1.6	--	2.5	--	--	2.8	--
AMAL	1.0	1.9	2.5	3.4	2.5	7.6	1.7	4.9	2.1	3.2	1.6	2.7
CESA	.1	7.5	13.2	57.2	123.9	162.7	150.2	252.3	183.6	154.6	113.0	114.9
HODI	3.4	7.7	10.7	4.9	5.8	1.5	12.6	1.7	2.5	3.3	1.8	4.7
PAMY	<.1	<.1	.4	.6	.7	1.2	1.6	2.5	2.2	4.3	5.8	6.7
PREM	--	--	--	--	--	--	--	--	.4	--	--	--
RIVI	--	--	--	--	--	1.3	--	--	--	--	--	--
ROGY	--	--	--	--	.2	.2	.2	.8	.3	.3	.2	.5
RUPA	1.0	.8	.4	1.1	1.9	1.6	1.3	4.3	3.1	1.9	1.0	1.5
SASC	3.8	31.4	24.8	44.8	27.1	48.9	28.4	48.9	47.9	52.1	74.7	88.1

Table 3-6.--Volume development of herb component (m³/0.01 ha), fig. 3-6

Species	Succession year											
	1	2	3	4	5	6	7	8	9	10	11	12
ANMA	--	--	--	--	--	--	--	--	0.4	0.6	--	--
APAN	0.3	0.2	0.1	1.0	2.0	1.5	1.4	2.8	3.6	5.9	5.9	4.4
ARNU	--	--	--	--	--	--	--	--	--	.2	.7	1.0
CARU	--	--	--	--	--	--	-	--	--	.2	--	.2
CARO	--	--	--	--	.1	.1	.3	.4	.3	.1	.4	.4
CAMI	--	--	--	--	--	--	--	--	--	--	.8	.5
DIHO	--	.4	.3	.3	.5	.6	.9	.9	1.2	.6	.4	1.4
EPAN	9.4	12.7	12.7	14.5	16.3	13.2	3.2	2.5	4.3	2.1	5.5	.8
FEAR	--	--	--	--	--	--	.1	.1	.2	.3	.4	.1
PTAQ	5.1	10.3	15.0	13.2	17.6	30.6	19.2	34.6	44.2	55.0	54.1	66.9
Misc.	.3	2.2	1.4	2.2	.6	.4	.3	.7	.3	--	.3	--

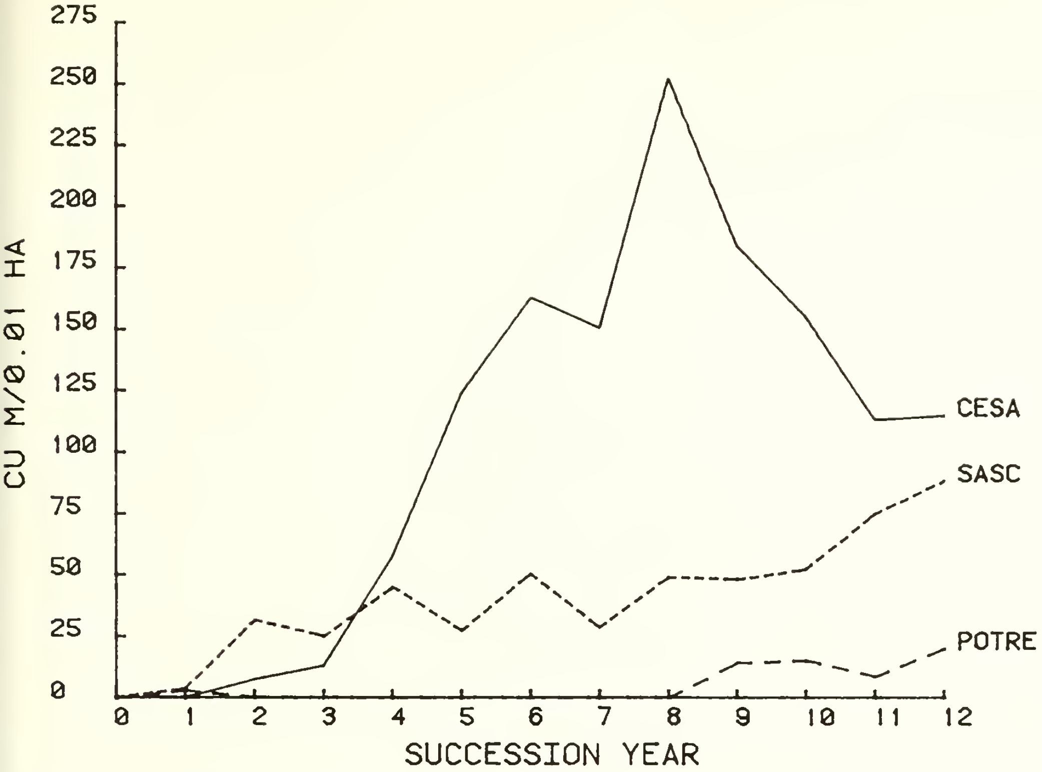


Figure 3-5.—Tree and shrub volume.

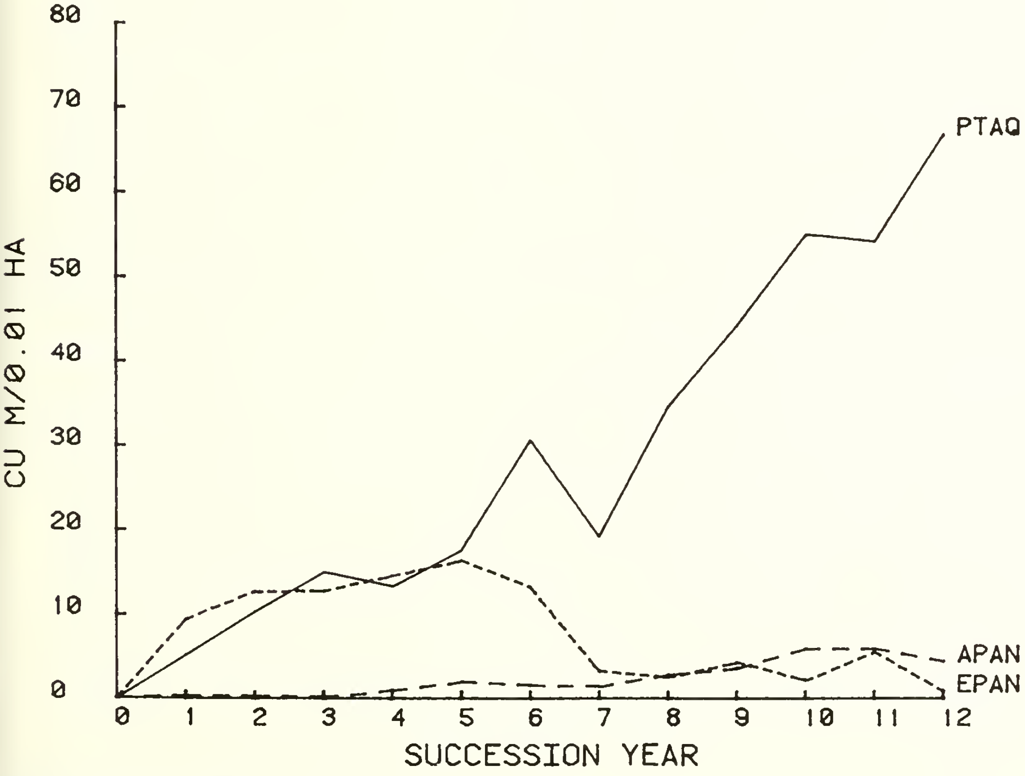


Figure 3-6.—Herb volume.

SUNDANCE BURN: 1802-16 Study Area SD-04

Site location and description: SE¼SE¼ sec. 8, T. 60 N., R. 2 W., BM; Elevation: 3,700 ft; Exposure: South (Az.
Slope: 30%

Forest cover type and tree size class: Western larch immature poletimber, 40 to 70% canopy coverage

Reconstructed prefire forest stand:
Tree component: Conifer density: 22.4/0.01 ha; Average d.b.h.: 15.4 cm; Basal area: 7,307 cm^2/0.01 ha
Shrub component: Species present: LOUT, PAMY, RUPA, VAME

Disturbance treatment:
Wildfire: September 1, 1967 (1800 hrs); Succession year 1:1968;
Fire intensity: 11,300 Btu/sec/ft; Rate of spread: 2.5 mi/h;
Fire severity: R-N index: 5-M; Overstory crown foliage: Consumed; Litter-duff: Consumed

Table 4-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 4-1

Life form component	Succession year													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Tree	--	--	<1	--	<1	--	--	1	5	9	10	11	23	27
Shrub	--	<1	5	9	17	15	15	30	30	32	32	38	48	70
Herb	29	52	48	47	56	48	53	53	62	62	55	60	60	63
Total veg.	29	52	53	57	73	63	69	84	96	103	97	110	131	160

Table 4-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 4-2

Life form component	Succession year													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Tree	--	--	<0.1	--	0.2	--	--	1.6	7.2	18.1	21.9	28.8	68.0	92.3
Shrub	--	0.2	2.0	4.8	11.2	10.8	9.0	33.2	33.8	41.9	42.9	45.9	68.1	114.7
Herb	5.6	17.2	18.5	21.4	23.7	18.7	19.1	20.6	27.7	26.0	24.0	29.1	30.2	38.7
Total veg.	5.6	17.4	20.5	26.2	35.1	29.5	28.1	55.5	68.6	86.0	88.8	103.8	166.2	245.6

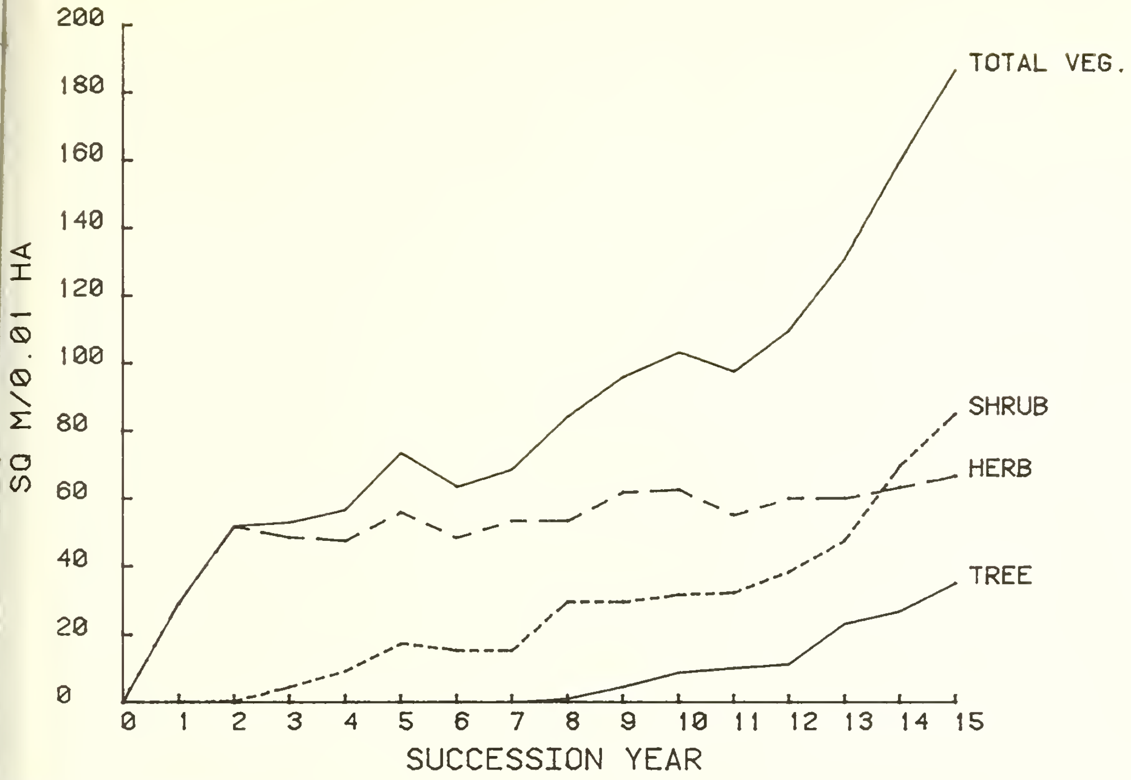


Figure 4-1.—Vegetative cover.

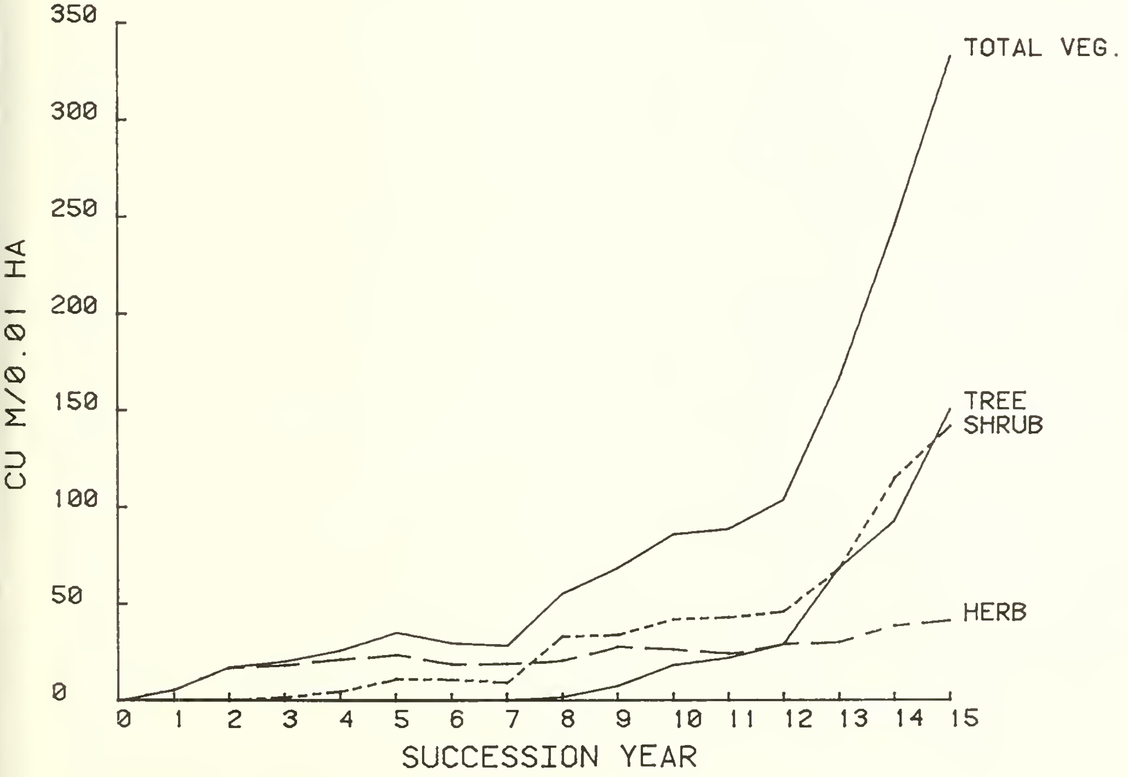


Figure 4-2.—Vegetative volume.

Table 4-3.--Cover development of tree and shrub components (m^2/0.01 ha or %), fig. 4-3

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tree															
PICO	--	--	--	--	--	--	--	--	2	5	5	5	13	15	21
PIMO	--	--	--	--	--	--	--	--	--	--	--	--	--	<1	--
POTRE	--	--	--	--	--	--	--	--	<1	<1	1	1	1	2	2
PSME	--	--	<1	--	<1	--	--	1	2	4	5	6	10	9	13
Shrub															
ALSI	--	--	--	--	--	--	--	3	3	3	4	7	11	18	21
CESA	--	--	--	--	--	--	--	7	5	7	8	6	14	15	18
LOUT	--	--	--	--	--	1	<1	1	1	1	1	2	2	3	6
PAMY	--	--	--	--	--	--	--	1	--	1	1	1	2	3	6
ROGY	--	--	<1	--	--	<1	<1	<1	<1	1	<1	<1	<1	<1	--
RUPA	--	--	--	--	--	--	--	--	--	<1	--	--	--	--	1
SASC	--	<1	4	9	17	14	14	16	16	16	16	18	15	27	31
VAME	--	--	--	--	--	--	1	2	4	2	2	5	3	3	3

Table 4-4.--Cover development of herb component (m^2/0.01 ha or %), fig. 4-4

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
ANMA	--	--	--	--	2	2	1	1	2	--	1	2	1	2	--
APAN	--	--	--	--	--	--	--	--	--	--	--	1	--	1	--
EPAN	18	32	31	28	29	19	11	12	12	12	8	11	8	6	2
PTAQ	9	17	16	17	24	25	38	37	47	47	40	46	52	54	63
VIOR	--	--	--	--	--	--	--	--	--	--	1	--	--	1	1
Misc.	2	2	2	2	1	2	3	4	1	4	5	--	--	--	--

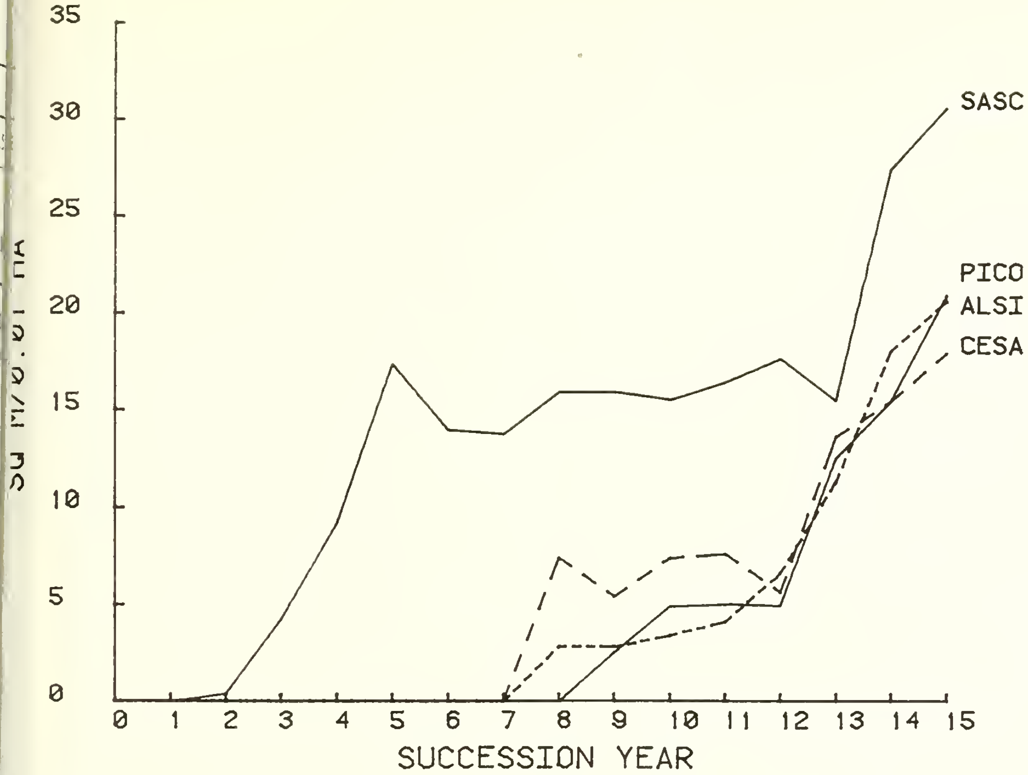


Figure 4-3.—Tree and shrub cover.

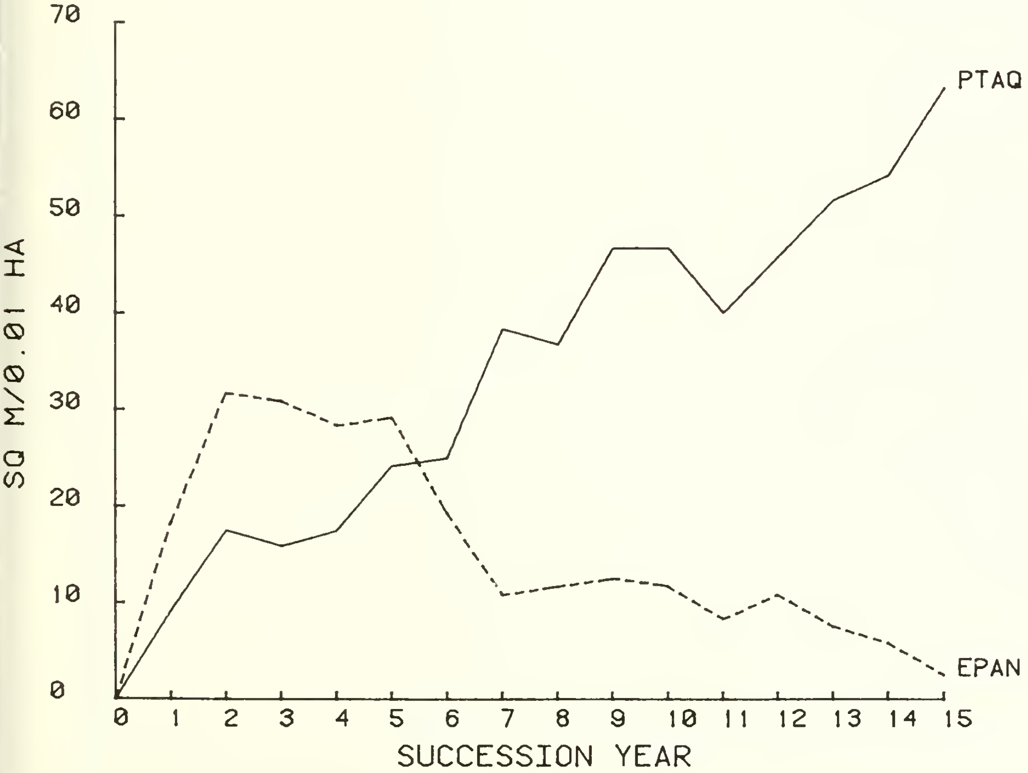


Figure 4-4.—Herb cover.

Table 4-5.--Volume development of tree and shrub components (m^3/0.01 ha), fig. 4-5

Species	Succession year 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Tree														
PICO	--	--	--	--	--	--	--	--	3.8	10.6	11.7	13.6	40.3	60.2
PIMO	--	--	--	--	--	--	--	--	--	--	--	--	--	.1
POTRE	--	--	--	--	--	--	--	--	.1	.3	1.0	1.3	2.4	4.0
PSME	--	--	<0.1	--	0.2	--	--	1.6	3.2	7.2	9.2	13.9	25.2	28.0
Shrub														
ALSI	--	--	--	--	--	--	--	7.6	7.6	9.0	10.0	15.6	18.8	35.2
CESA	--	--	--	--	--	--	--	10.5	9.3	14.4	15.8	9.6	28.9	40.7
LOUT	--	--	--	--	--	0.4	0.1	.3	.7	.8	.9	1.8	2.6	2.3
PAMY	--	--	--	--	--	--	--	.5	--	.2	.2	.2	.5	1.3
ROGY	--	--	.2	--	--	.1	.2	.3	.2	.7	.4	.3	.2	.3
RUPA	--	--	--	--	--	--	--	--	--	.2	--	--	--	--
SASC	--	0.2	1.9	4.8	11.2	10.3	8.4	13.6	14.9	15.9	15.4	16.9	16.0	33.7
VAME	--	--	--	--	--	--	.3	.4	1.2	.7	.3	1.6	1.2	1.2

Table 4-6.--Volume development of herb component (m^3/0.01 ha), fig. 4-6

Species	Succession year 1	2	3	4	5	6	7	8	9	10	11	12	13	14
ANMA	--	--	--	--	0.6	1.3	0.1	0.2	0.5	--	0.2	0.7	0.2	0.7
APAN	--	--	--	--	--	--	--	--	--	--	--	.3	--	.1
EPAN	3.6	11.5	13.0	15.2	14.6	8.4	3.8	6.0	6.8	6.3	4.8	8.7	5.3	3.2
PTAQ	1.9	5.2	5.1	5.7	8.4	8.8	14.8	13.2	20.2	18.7	17.7	19.4	24.6	34.6
VIOR	--	--	--	--	--	--	--	--	--	--	<.1	--	--	<.1
Misc.	.2	.5	.4	.4	.2	.3	.4	1.3	.1	.9	1.2	--	--	--

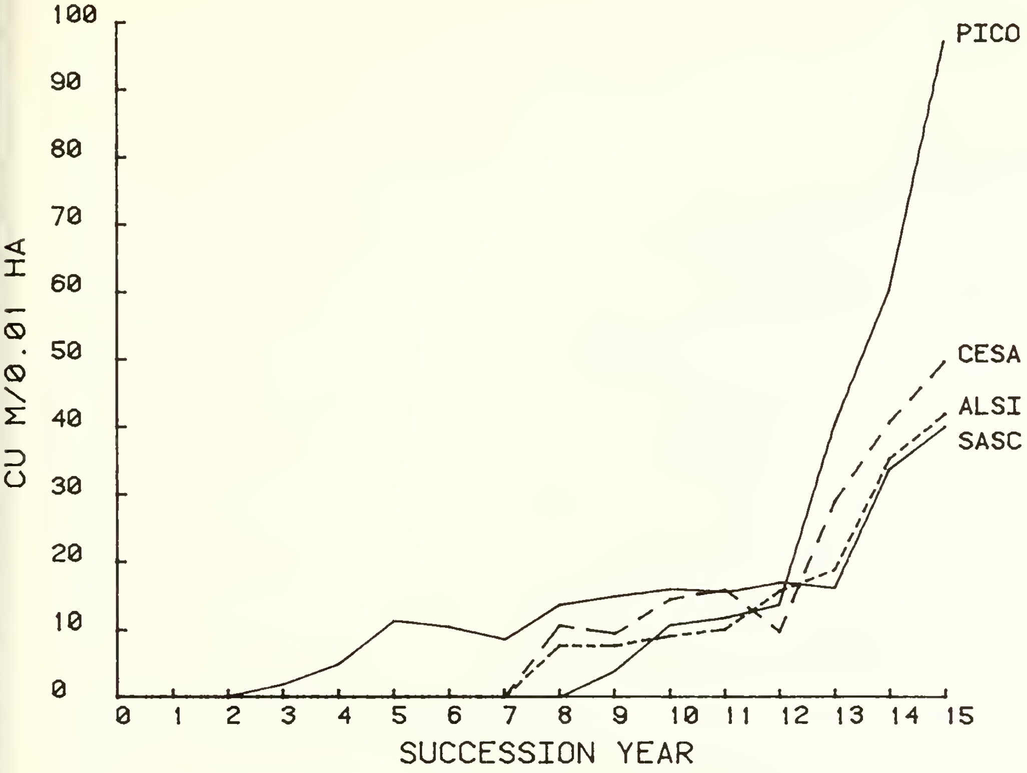


Figure 4-5.—Tree and shrub volume.

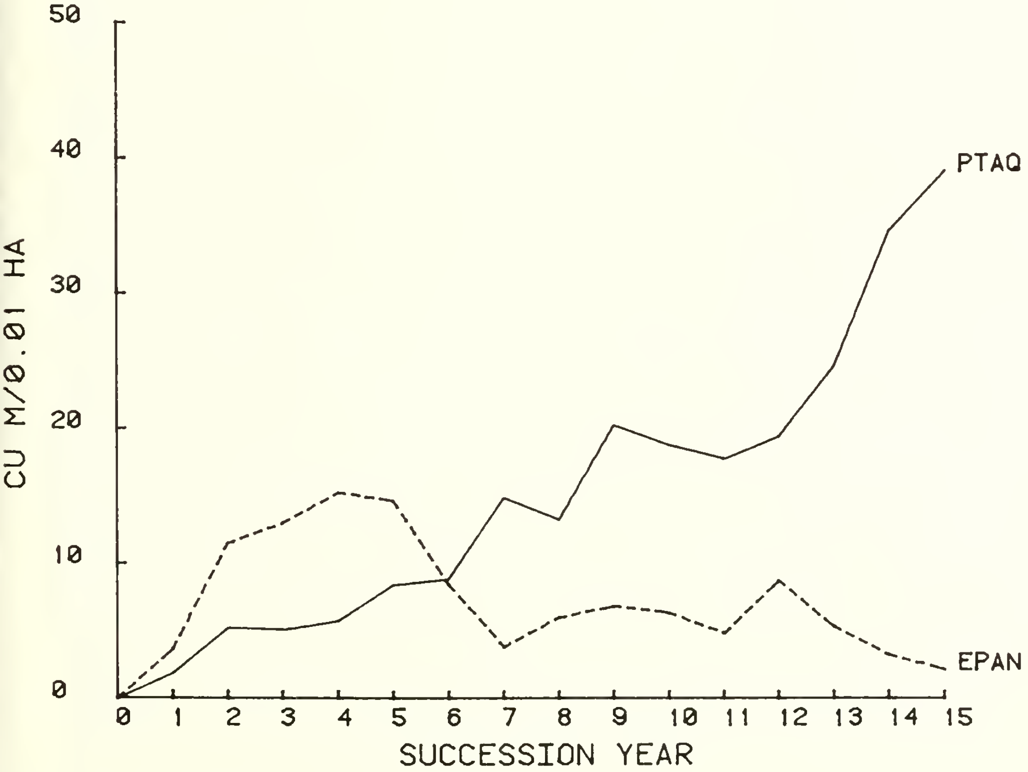


Figure 4-6.—Herb volume.

SUNDANCE BURN: 1802-16 Study Area SD-05

Site location and description: NE¼SW¼ sec. 8, T. 60 N., R. 2 W., BM; Elevation: 3,950 ft; Exposure: East (Az.
Slope: 25%

Forest cover type and tree size class: Western larch immature poletimber, 40 to 70% canopy coverage

Reconstructed prefire forest stand:
Tree component: Conifer density: 14.4/0.01 ha; Average d.b.h.: 12.8 cm; Basal area: 2,571 cm²/0.01 ha
Shrub component: ALSI 60%, RUPA 20%, SASC 20% (Shrub density: 2.0/0.01 ha);
Other species present: ACGL, PAMY, ROGY, SOSC, VAME

Disturbance treatment:
Wildfire: September 1, 1967 (1800 hrs); Succession year 1:1968;
Fire intensity: 11,300 Btu/sec/ft; Rate of spread: 2.5 mi/h;
Fire severity: R-N index: 5-M; Overstory crown foliage: Consumed; Litter: Consumed; Duff: Almost complete
consumed

Table 5-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 5-1

Life form component	Succession year													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Tree	--	--	--	--	--	--	--	--	<1	1	3	5	6	11
Shrub	1	10	11	10	19	27	34	38	37	27	34	28	39	52
Herb	65	82	75	68	77	56	68	70	75	80	77	65	74	81
Total veg.	66	93	86	79	96	83	102	108	113	107	113	99	119	144

Table 5-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 5-2

Life form component	Succession year													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Tree	--	--	--	--	--	--	--	--	0.8	1.1	6.7	13.4	17.4	31.3
Shrub	0.2	8.1	8.1	8.6	21.4	30.1	36.4	51.1	45.2	39.1	41.6	30.2	51.9	75.2
Herb	19.1	55.2	49.9	43.3	47.5	32.7	38.7	39.6	46.6	56.9	46.3	42.9	48.2	59.3
Total veg.	19.3	63.2	58.0	52.0	68.8	62.8	75.1	90.7	92.6	97.1	94.7	86.6	117.5	165.7

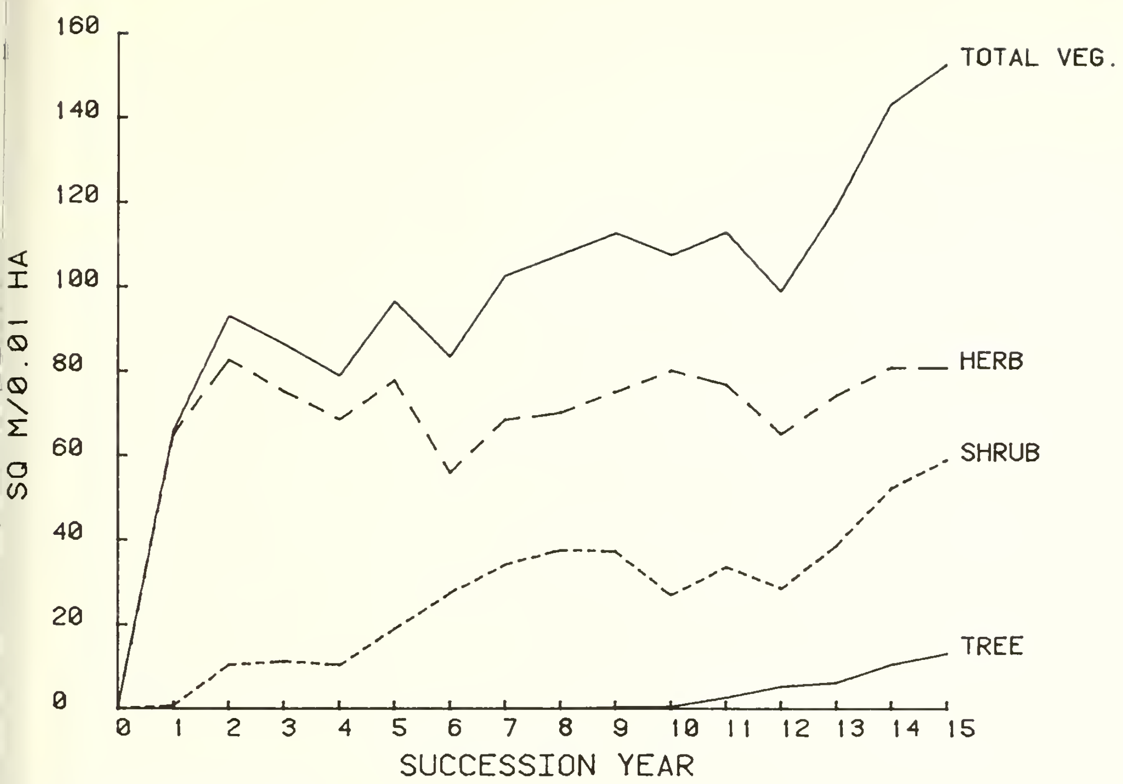


Figure 5-1.—Vegetative cover.

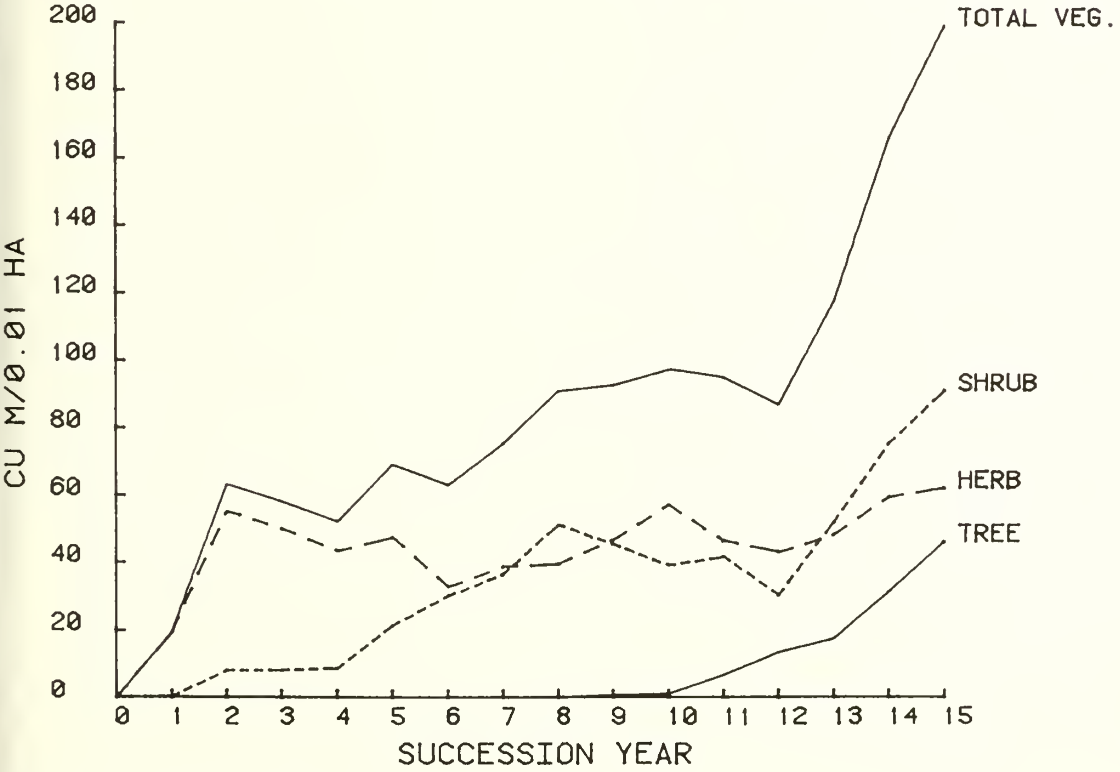


Figure 5-2.—Vegetative volume.

Table 5-3.--Cover development of tree and shrub components (m^2/0.01 ha or %), fig. 5-3

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tree															
POTRE	--	--	--	--	--	--	--	--	<1	1	1	1	1	1	1
PSME	--	--	--	--	--	--	--	--	--	--	2	4	6	10	12
Shrub															
ALSI	--	2	--	--	2	--	5	3	2	6	3	3	8	7	12
PAMY	--	--	--	--	1	1	1	1	3	1	2	2	2	<1	2
RUPA	1	5	3	2	2	2	5	4	3	3	3	3	2	5	8
SASC	--	4	8	9	14	23	23	28	29	17	24	18	24	36	34
VAME	--	--	--	--	--	1	--	2	1	1	2	2	2	4	3

Table 5-4.--Cover development of herb component (m^2/0.01 ha or %), fig. 5-4

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
ANMA	--	--	--	--	--	1	3	2	2	2	--	1	2	2	3
APAN	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1
CARO	--	--	--	--	--	--	1	--	1	1	1	1	1	1	--
DIHO	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--
EPAN	46	52	46	39	37	18	18	22	19	17	17	12	8	11	8
FEAR	--	--	--	--	--	--	1	--	--	--	1	1	--	--	--
HIAL	--	--	--	--	--	--	--	--	--	--	3	2	3	2	3
PTAQ	17	30	29	28	38	36	44	42	52	57	52	47	58	60	62
SMST	--	--	--	--	1	--	1	1	1	2	1	2	1	2	1
THOC	--	--	--	--	--	--	--	--	--	--	--	1	2	2	2
TRRE	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--
Misc.	2	1	--	1	1	1	--	3	--	2	2	--	--	1	--

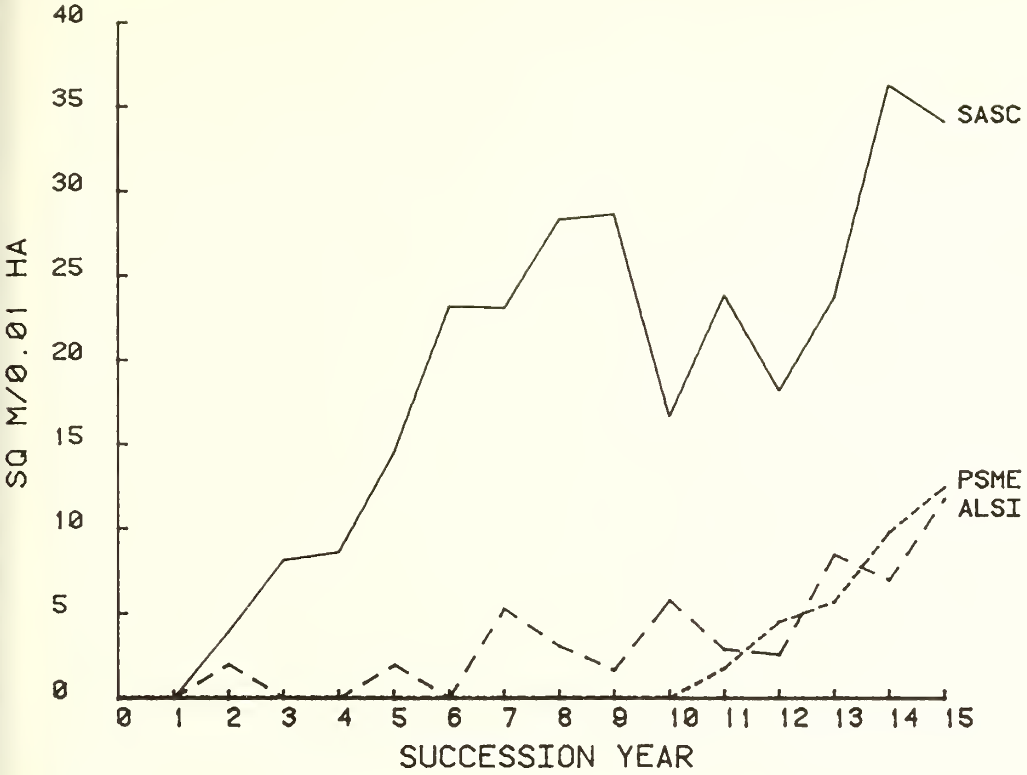


Figure 5-3.—Tree and shrub cover.

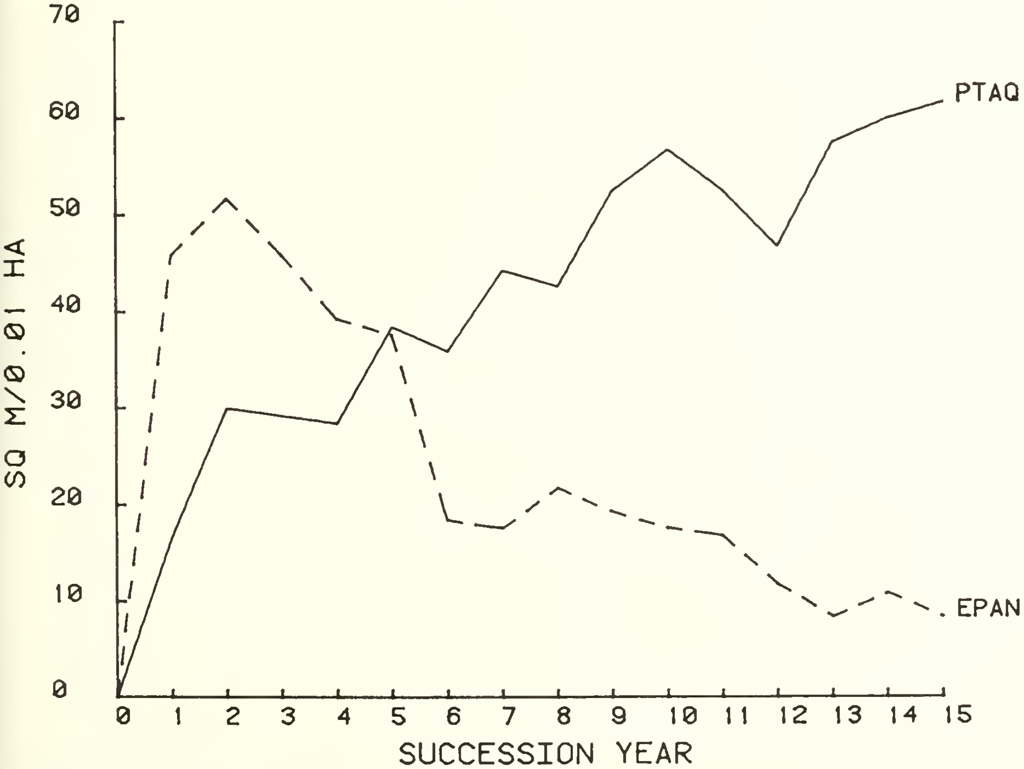


Figure 5-4.—Herb cover.

Table 5-5.--Volume development of tree and shrub components (m^3/0.01 ha), fig. 5-5

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
Tree															
POTRE	--	--	--	--	--	--	--	--	0.8	1.1	2.0	1.6	1.2	1.6	5
PSME	--	--	--	--	--	--	--	--	--	--	4.8	11.9	16.2	29.7	4.7
Shrub															
ALSI	--	2.5	--	--	3.5	--	10.5	7.8	4.7	13.0	4.5	4.4	18.4	12.0	27.5
PAMY	--	--	--	--	.1	0.1	.3	.6	1.1	.3	.9	.9	.9	.2	6
RUPA	0.2	2.1	1.4	0.3	.4	.5	1.4	1.3	1.3	1.1	.8	1.0	.9	1.8	3.3
SASC	--	3.4	6.7	8.3	17.3	29.3	24.2	40.6	37.7	24.4	35.2	23.4	30.9	60.1	57.9
VAME	--	--	--	--	--	.2	--	.8	.4	.3	.3	.5	.7	1.1	1.4

Table 5-6.--Volume development of herb component (m^3/0.01 ha), fig. 5-6

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1
ANMA	--	--	--	--	--	0.4	1.1	0.6	0.5	0.8	--	0.3	1.0	1.7	1
APAN	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
CARO	--	--	--	--	--	--	.2	--	.1	.1	.1	.1	.1	.1	--
DIHO	--	--	--	--	--	--	--	--	--	--	--	--	--	.1	--
EPAN	13.8	38.1	29.2	25.8	21.7	9.4	9.1	12.1	11.1	14.3	9.5	9.2	4.8	6.2	5.
FEAR	--	--	--	--	--	--	.1	--	--	--	.2	.2	--	--	--
HIAL	--	--	--	--	--	--	--	--	--	--	.2	.1	.2	.1	.
PTAQ	4.6	16.9	20.7	17.4	25.7	22.7	27.9	26.2	34.7	40.7	35.8	32.0	41.0	49.4	52.
SMST	--	--	--	--	.1	--	.1	.1	.1	.3	.2	.3	.1	.3	.
THOC	--	--	--	--	--	--	--	--	--	--	--	.6	1.0	1.3	1.
TRRE	--	--	--	--	--	--	.2	--	--	--	--	--	--	--	--
Misc.	.7	.2	--	.1	.1	.1	--	.7	--	.7	.4	--	--	<.1	--

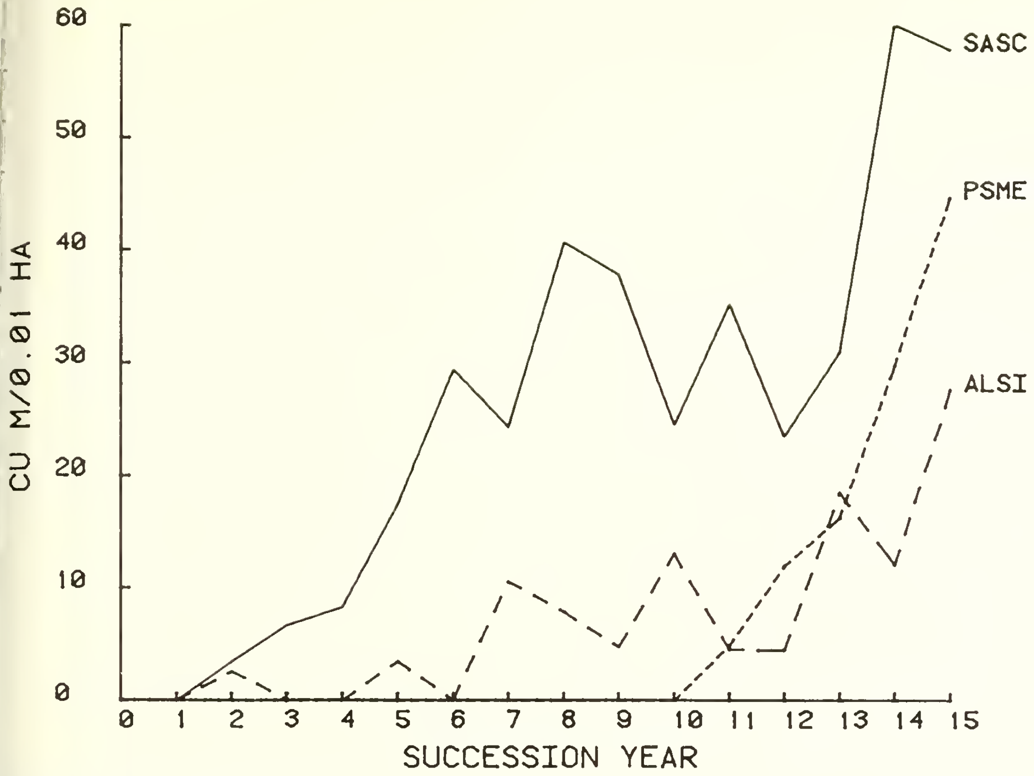


Figure 5-5.—Tree and shrub volume.

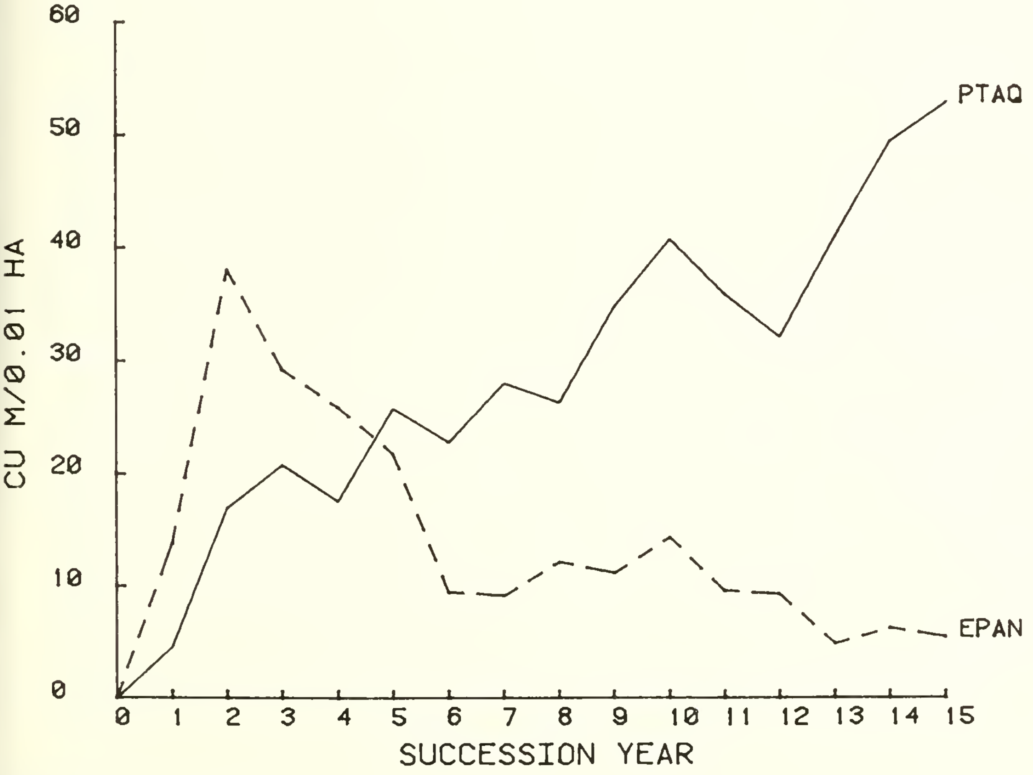


Figure 5-6.—Herb volume.

SUNDANCE BURN: 1802-16 Study Area SD-06

Site location and description: SE¼NW¼ sec. 8, T. 60 N., R. 2 W., BM; Elevation: 4,200 ft; Exposure: North (Az.
Slope: 30%

Forest cover type and tree size class: Western hemlock mature sawtimber, 40 to 70% canopy coverage

Reconstructed prefire forest stand:
Tree component: Conifer density: 2.4/0.01 ha; Average d.b.h.: 43.7 cm; Basal area: 4,139 cm^2/0.01 ha
Shrub component: Species present: VAME

Disturbance treatment:
Wildfire: September 1, 1967 (1800-1900 hrs); Succession year 1:1968;
Fire intensity: 3,400 to 11,300 Btu/sec/ft; Rate of spread: 1 to 2.5 mi/h;
Fire severity: R-N index: 5-M; Overstory crown foliage: Consumed; Litter-duff: Consumed

Table 6-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 6-1

Life form component	Succession year													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Tree	--	--	--	--	--	--	--	1	1	5	7	8	14	11
Shrub	1	3	10	17	16	22	23	27	25	24	26	30	38	46
Herb	6	34	28	25	23	14	23	21	27	28	26	30	25	28
Total veg.	7	37	39	42	39	36	46	48	53	56	59	68	77	84

Table 6-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 6-2

Life form component	Succession year													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Tree	--	--	--	--	--	--	--	0.2	0.3	4.2	8.0	10.4	24.0	27.7
Shrub	0.1	1.6	5.6	12.6	13.1	18.8	18.2	22.2	20.5	23.8	22.0	28.2	35.4	51.0
Herb	.5	14.2	12.2	10.0	9.8	4.4	8.4	8.4	9.9	12.4	7.9	12.8	9.4	10.3
Total veg.	.6	15.8	17.8	22.6	23.0	23.2	26.7	30.7	30.7	40.5	37.9	51.4	68.8	89.0

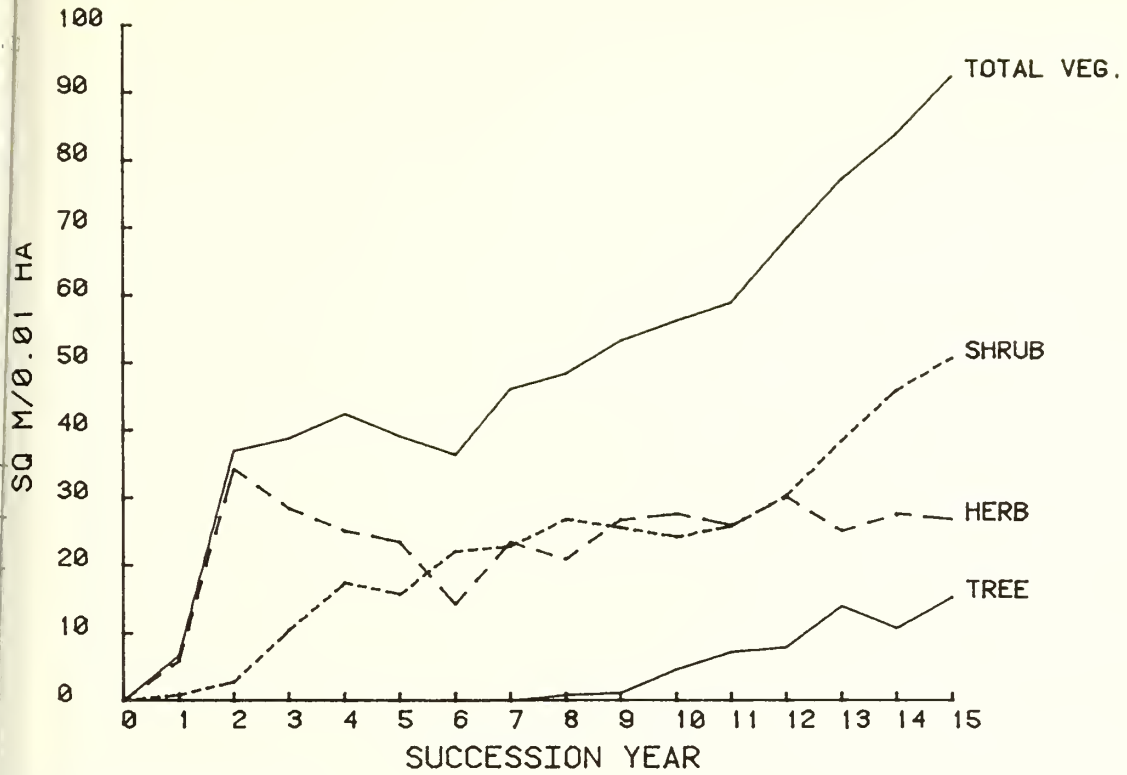


Figure 6-1.—Vegetative cover.

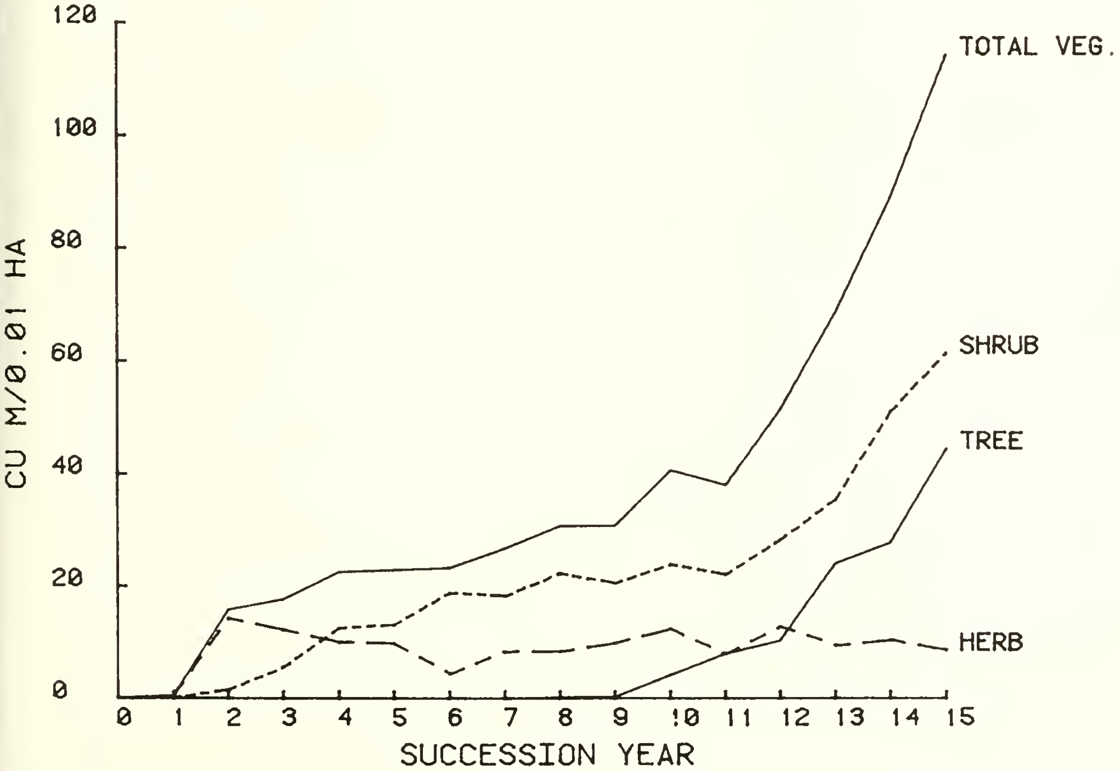


Figure 6-2.—Vegetative volume.

Table 6-3.--Cover development of tree and shrub components ($m^2/0.01$ ha or %), fig. 6-3

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tree															
ABGR	--	--	--	--	--	--	--	1	1	2	2	2	3	--	--
LAOC	--	--	--	--	--	--	--	--	--	--	--	--	<1	1	<1
PIMO	--	--	--	--	--	--	--	--	--	--	--	--	--	1	2
POTRE	--	--	--	--	--	--	--	--	<1	<1	--	<1	1	--	<1
PSME	--	--	--	--	--	--	--	--	--	3	6	6	9	9	13
Shrub															
PAMY	--	--	--	--	--	--	--	1	1	1	--	--	3	2	4
SASC	1	3	10	17	16	22	23	26	25	23	26	30	36	43	43
VAME	--	--	--	--	--	--	--	--	--	--	--	--	--	1	4

Table 6-4.--Cover development of herb component ($m^2/0.01$ ha or %), fig. 6-4

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
ANMA	--	--	--	--	--	--	1	2	2	7	8	8	7	8	6
EPAN	6	34	28	25	22	14	22	18	20	13	11	10	7	9	8
HIAL	--	--	--	--	--	--	--	--	1	5	6	10	11	8	8
VIOR	--	--	--	--	--	--	--	--	--	--	--	--	--	2	2
Misc.	--	--	--	--	1	--	1	2	3	2	1	2	1	--	2

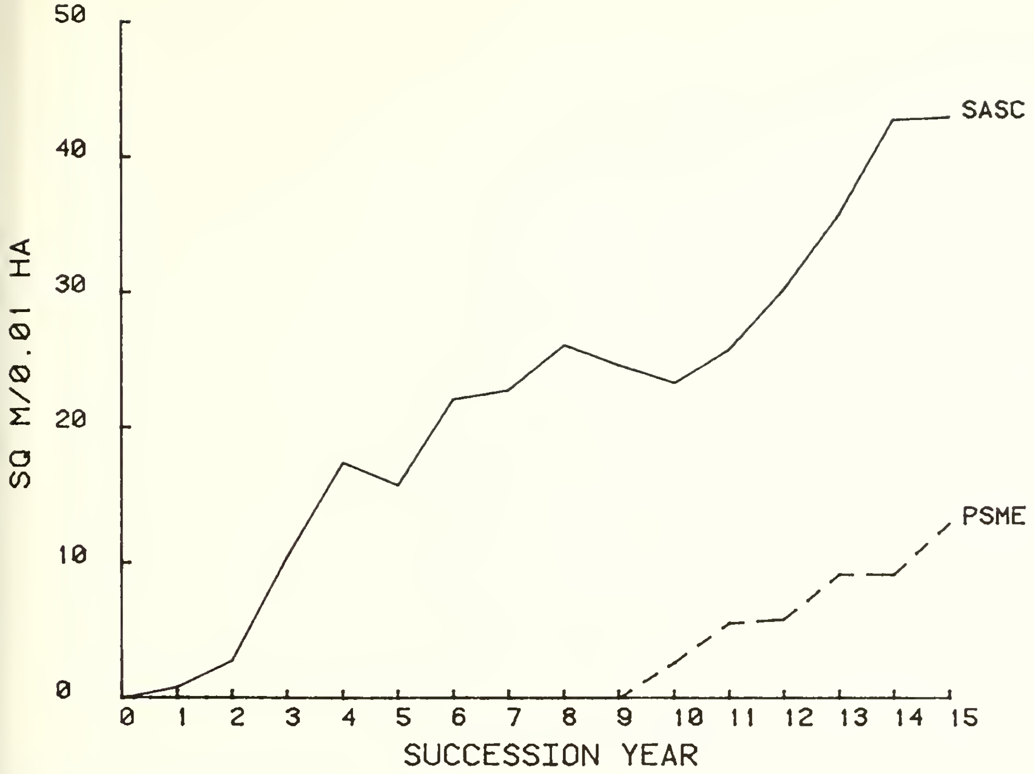


Figure 6-3.—Tree and shrub cover.

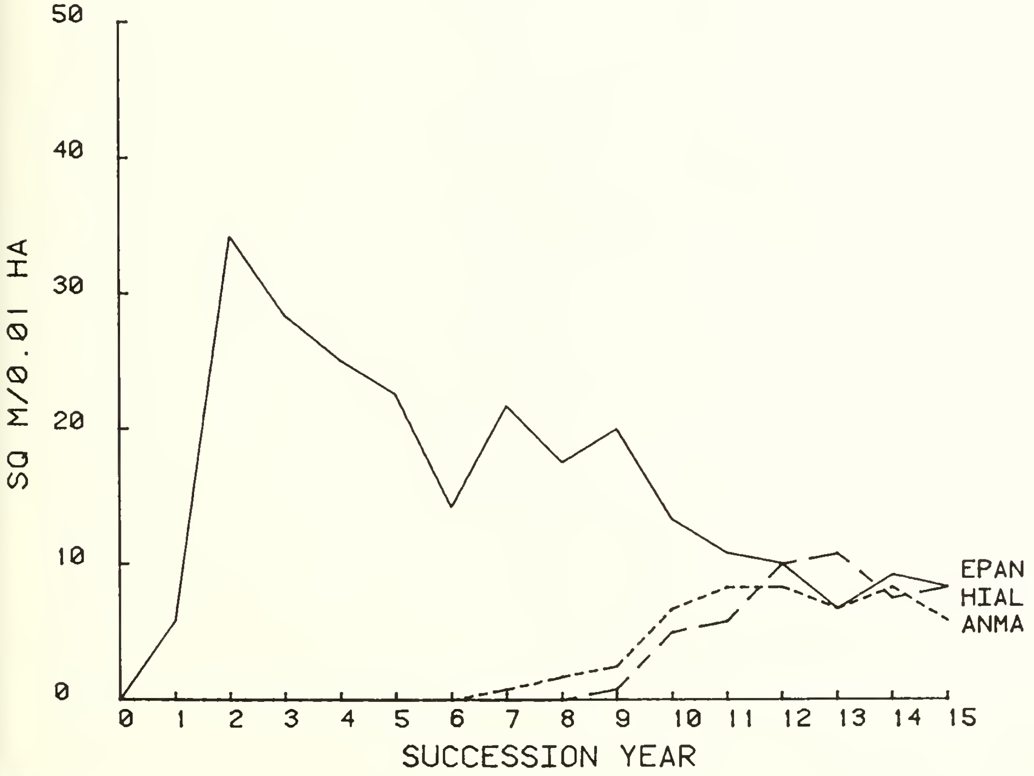


Figure 6-4.—Herb cover.

Table 6-5.--Volume development of tree and shrub components (m^3/0.01 ha), fig. 6-5

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tree															
ABGR	--	--	--	--	--	--	--	0.2	0.2	0.5	0.7	0.7	2.5	--	--
LAOC	--	--	--	--	--	--	--	--	--	--	--	--	.7	1.4	1.1
PIMO	--	--	--	--	--	--	--	--	--	--	--	--	--	.5	1.3
POTRE	--	--	--	--	--	--	--	--	.1	.2	--	.2	.6	--	.4
PSME	--	--	--	--	--	--	--	--	--	3.5	7.3	9.5	20.2	25.8	41.6
Shrub															
PAMY	--	--	--	--	--	--	--	.3	.4	.5	--	--	1.5	1.5	2.4
SASC	0.1	1.6	5.6	12.6	13.1	18.8	18.2	21.8	20.1	23.3	22.0	28.2	33.9	49.2	55.4
VAME	--	--	--	--	--	--	--	--	--	--	--	--	--	.3	3.5

Table 6-6.--Volume development of herb component (m^3/0.01 ha), fig. 6-6

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
ANMA	--	--	--	--	--	--	0.3	0.8	1.1	2.9	3.1	2.8	2.6	3.6	2.4
EPAN	0.5	14.2	12.2	10.0	9.6	4.4	7.9	7.2	8.1	6.9	3.7	6.0	3.0	3.7	4.6
HIAL	--	--	--	--	--	--	--	--	<.1	1.6	.9	3.5	3.5	2.9	1.2
VIOR	--	--	--	--	--	--	--	--	--	--	--	--	--	.1	.1
Misc.	--	--	--	--	.2	--	.2	.4	.6	1.0	.2	.5	.3	--	.2

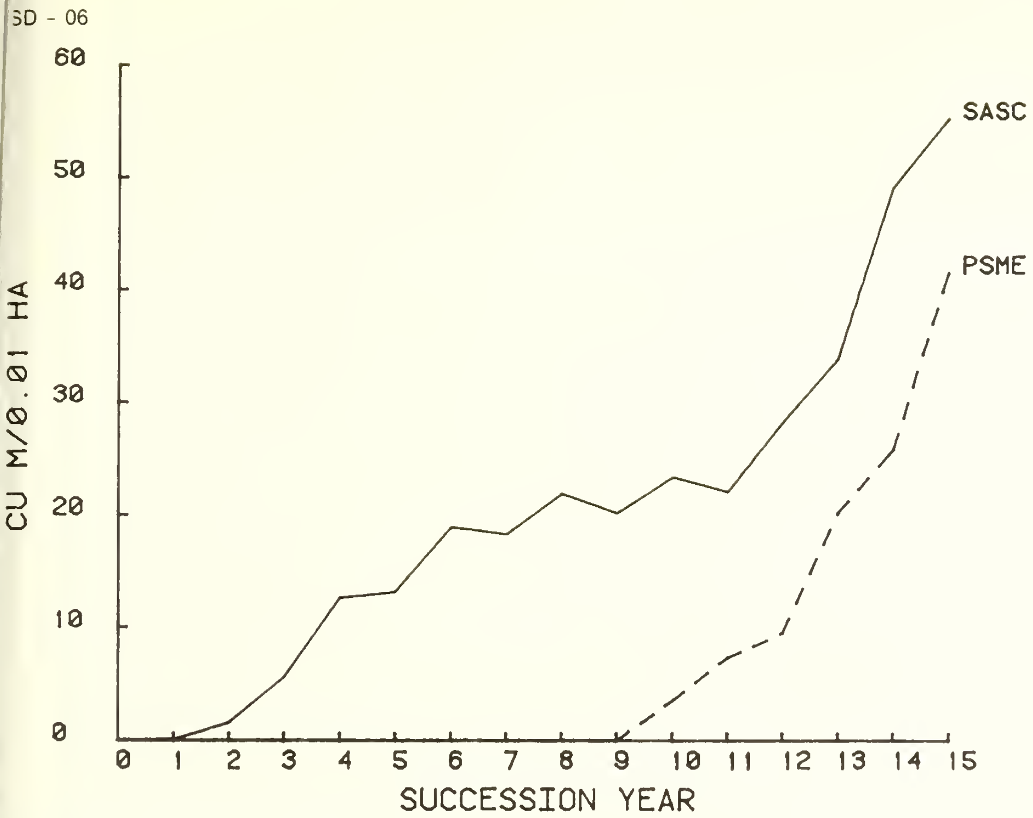


Figure 6-5.—Tree and shrub volume.

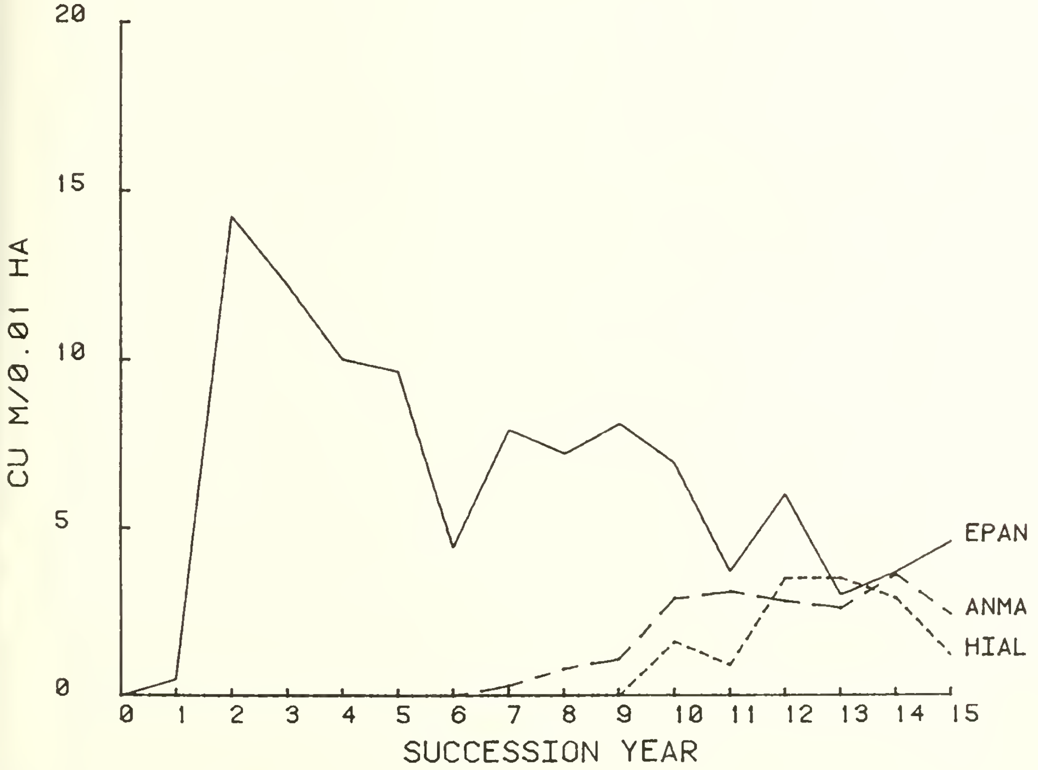


Figure 6-6.—Herb volume.

SUNDANCE BURN: 1802-16 Study Area SD-07

Site location and description: SW¼NW¼ sec. 8, T. 60 N., R. 2 W., BM; Elevation: 4,300 ft; Exposure: Southeast (Az. 130°); Slope: 15%

Forest cover type and tree size class: Western redcedar mature sawtimber, 70 through 100% canopy coverage

Reconstructed prefire forest stand:
Tree component: Conifer density: 0.4/0.01 ha; Average d.b.h.: 56.0 cm; Basal area: 985 cm^2/0.01 ha
Shrub component: Species present: RULE, RUPA, SARA, VAME

Disturbance treatment:
Clearcut: Mature *Thuja plicata* forest logged prior to fire;
Wildfire: September 1, 1967 (1800 hrs); Succession year 1:1968;
Fire intensity: 11,300 Btu/sec/ft; Rate of spread: 2.5 mi/h;
Fire severity: R-N index: 3-M; Litter-duff: Consumed

Table 7-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 7-1

ife form	Succession year													
omponent	1	2	3	4	5	6	7	8	9	10	11	12	13	14
ree	--	--	--	--	--	--	--	<1	1	1	4	6	5	6
hrub	2	8	7	13	22	29	31	40	44	46	45	47	65	97
erb	32	73	40	37	33	33	38	37	35	39	39	37	42	41
otal veg.	33	82	47	51	55	62	70	77	80	86	88	89	111	144

able 7-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 7-2

ife form	Succession year													
omponent	1	2	3	4	5	6	7	8	9	10	11	12	13	14
ree	--	--	--	--	--	--	--	0.1	0.4	1.3	4.2	8.9	9.3	16.0
hrub	0.2	4.4	5.3	8.1	15.0	23.9	22.9	42.9	46.3	44.4	34.9	34.3	50.8	100.1
erb	11.1	59.9	23.5	18.5	16.2	15.9	19.7	15.3	13.8	15.7	16.8	20.4	19.2	19.0
otal veg.	11.2	64.4	28.8	26.6	31.2	39.8	42.6	58.3	60.4	61.4	55.9	63.6	79.3	135.1

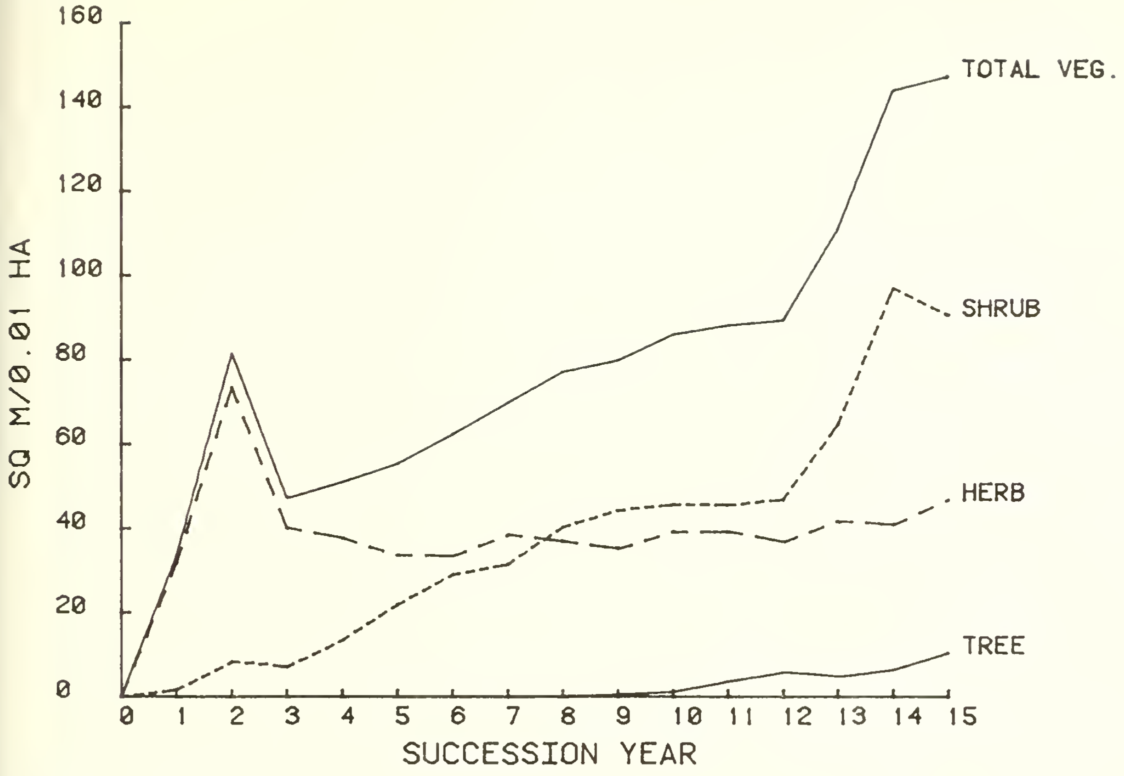


Figure 7-1.—Vegetative cover.

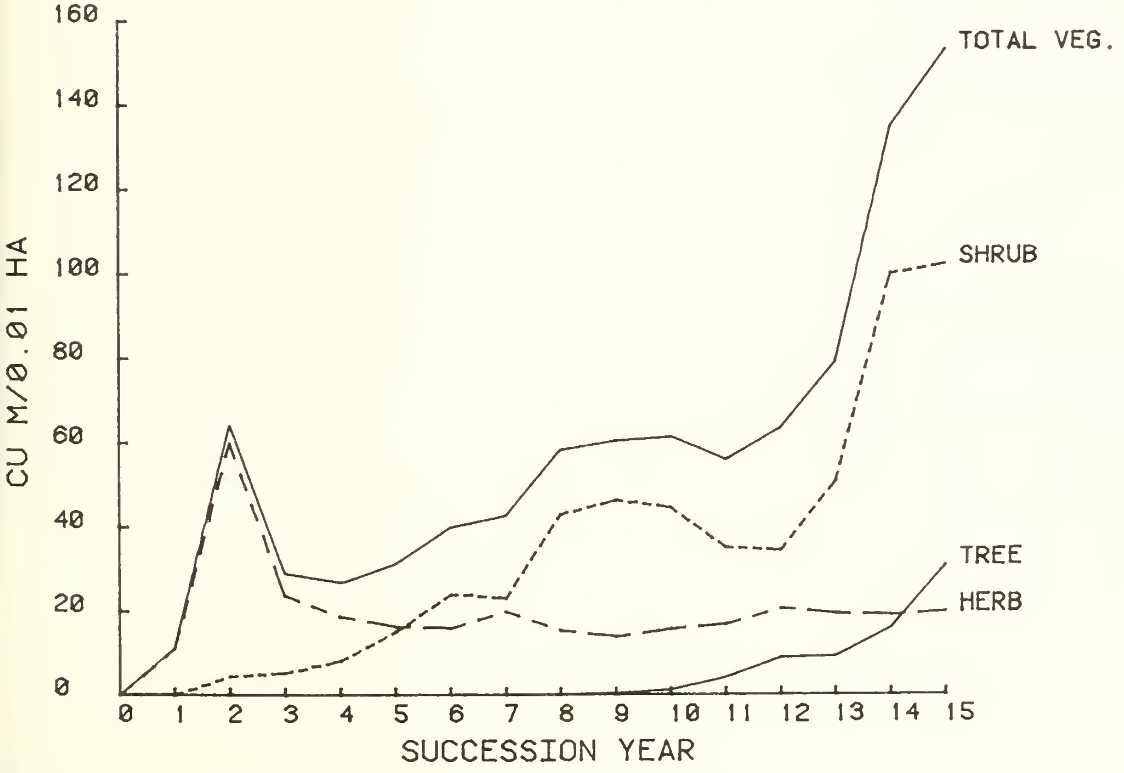


Figure 7-2.—Vegetative volume.

Table 7-3.--Cover development of tree and shrub components (m^2/0.01 ha or %), fig. 7-3

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tree															
LAOC	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1
PIEN	--	--	--	--	--	--	--	<1	1	1	4	5	3	3	4
PICO	--	--	--	--	--	--	--	--	--	--	--	--	1	1	1
PIMO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	<1
POTRE	--	--	--	--	--	--	--	--	--	--	--	--	--	<1	<1
PSME	--	--	--	--	--	--	--	--	--	--	--	1	1	2	4
Shrub															
PAMY	--	--	--	--	2	1	2	2	3	7	14	19	30	39	37
RULE	--	--	--	1	1	2	--	--	1	1	--	1	--	--	--
RUPA	2	6	2	5	5	8	11	12	11	11	10	8	10	12	12
SASC	--	2	4	8	14	18	18	26	28	27	21	19	25	45	41
SARA	--	<1	1	--	--	--	1	1	1	--	1	<1	1	<1	<1

Table 7-4.--Cover development of herb component (m^2/0.01 ha or %), fig. 7-4

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
AGAL	--	--	--	--	--	--	--	--	--	--	--	--	1	1	1
ANMA	--	--	--	--	1	2	8	13	13	16	13	5	4	8	7
CARO	--	--	--	--	--	--	1	--	1	--	1	1	1	1	2
CIAR	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--
CLUN	--	--	--	--	--	--	--	--	--	1	1	1	2	1	2
DIHO	--	--	--	--	1	1	2	1	2	1	1	1	--	1	2
EPAN	30	72	37	32	32	24	26	19	15	13	16	18	14	14	11
ERAC	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--
FEAR	--	--	--	--	--	--	--	--	--	--	1	2	2	2	2
HIAL	--	--	--	--	--	--	--	--	--	1	2	6	6	5	2
PHPR	--	--	--	--	--	--	1	--	--	--	1	1	--	--	--
PTAQ	1	--	1	3	--	4	--	2	2	3	2	1	11	6	18
SMST	--	--	--	--	--	--	--	--	--	--	--	1	1	1	1
SOCA	--	--	--	--	--	--	--	--	--	--	--	--	--	1	1
VIOR	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1
Misc.	1	1	2	2	--	2	1	1	2	4	1	--	1	--	--

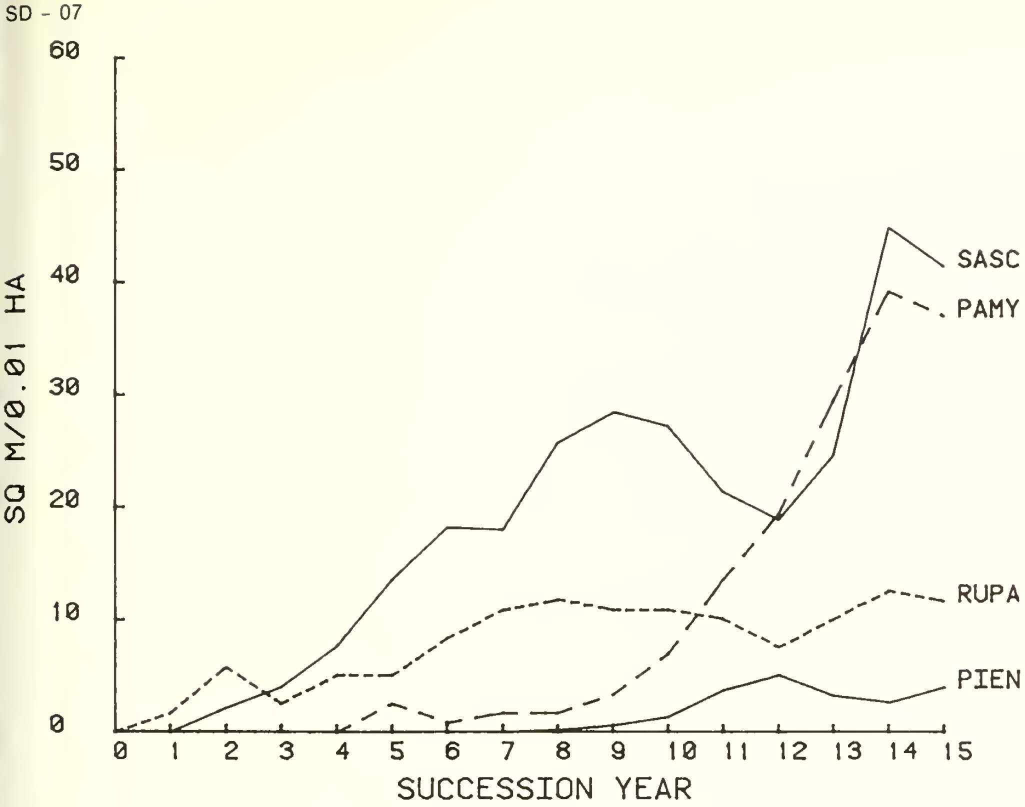


Figure 7-3.—Tree and shrub cover.

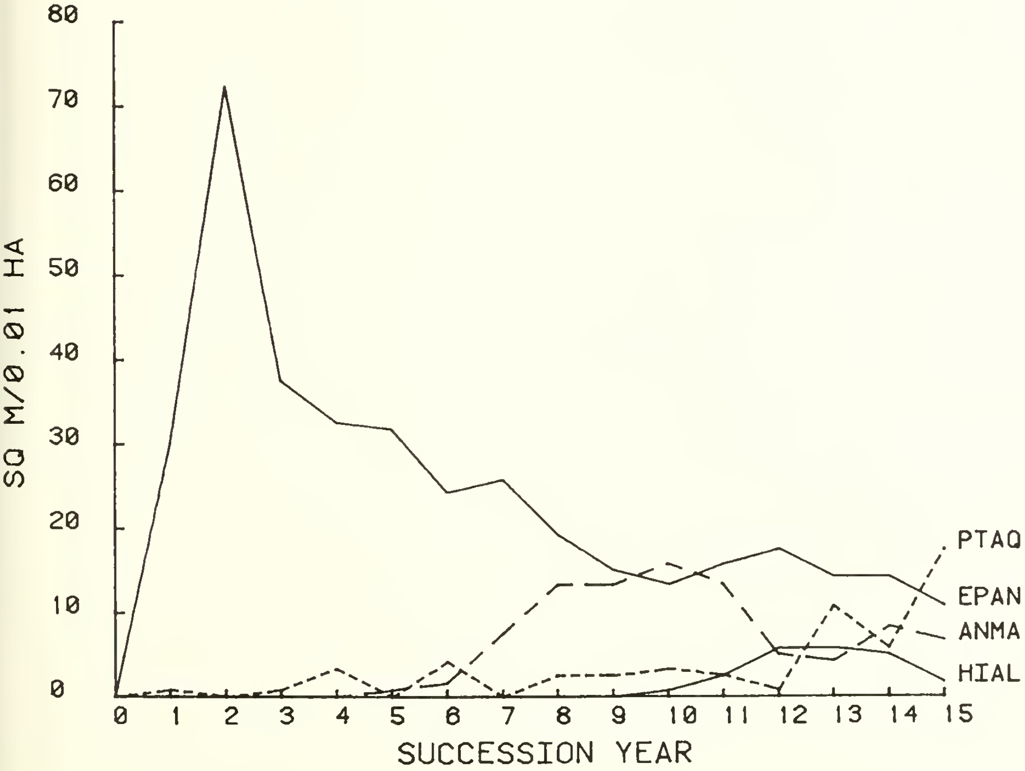


Figure 7-4.—Herb cover.

Table 7-5.--Volume development of tree and shrub components (m^3/0.01 ha), fig. 7-5

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tree															
LAOC	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2.4
PIEN	--	--	--	--	--	--	--	0.1	0.4	1.3	4.2	7.1	6.2	5.8	9.6
PICO	--	--	--	--	--	--	--	--	--	--	--	--	1.4	3.0	3.3
PIMO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	.1
POTRE	--	--	--	--	--	--	--	--	--	--	--	--	--	.8	1.8
PSME	--	--	--	--	--	--	--	--	--	--	--	1.8	1.7	6.4	13.7
Shrub															
PAMY	--	--	--	--	0.4	0.1	0.3	.3	.9	2.6	5.9	9.3	15.0	23.1	23.7
RULE	--	--	--	0.1	.2	.6	--	--	.4	.2	--	.2	--	--	--
RUPA	0.2	2.1	0.8	.6	.9	1.3	2.3	2.5	2.3	2.0	1.8	1.2	2.2	3.6	3.5
SASC	--	2.1	4.2	7.4	13.5	21.9	19.7	39.1	41.9	39.7	26.9	23.3	33.3	73.2	74.9
SARA	--	.2	.3	--	--	--	.6	1.0	.7	--	.3	.3	.3	.1	.3

Table 7-6.--Volume development of herb component (m^3/0.01 ha), fig. 7-6

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
AGAL	--	--	--	--	--	--	--	--	--	--	--	--	0.4	0.6	0.4
ANMA	--	--	--	--	0.2	0.8	3.0	4.7	4.6	5.3	4.9	1.1	1.3	3.7	3.0
CARO	--	--	--	--	--	--	.2	--	.1	--	.1	.1	.1	.1	.2
CIAR	--	--	--	--	--	--	.1	--	--	--	--	--	--	--	--
CLUN	--	--	--	--	--	--	--	--	--	.1	.2	<.1	.1	<.1	.1
DIHO	--	--	--	--	.4	.3	.7	.4	.7	.3	.4	.4	--	.3	.6
EPAN	10.7	59.4	22.9	17.2	15.7	13.3	14.9	9.4	7.4	8.1	8.3	12.8	8.1	7.5	6.6
ERAC	--	--	--	--	--	--	--	--	--	--	--	.4	--	--	--
FEAR	--	--	--	--	--	--	--	--	--	--	.5	.6	.5	1.0	.6
HIAL	--	--	--	--	--	--	--	--	--	.2	.8	3.8	3.9	3.0	.2
PHPR	--	--	--	--	--	--	.8	--	--	--	.8	.6	--	--	--
PTAQ	.2	--	.4	.8	--	1.0	--	.4	.7	.8	.6	.3	4.5	2.4	7.8
SMST	--	--	--	--	--	--	--	--	--	--	--	.2	.2	.2	.2
SOCA	--	--	--	--	--	--	--	--	--	--	--	--	--	.3	.4
VIOR	--	--	--	--	--	--	--	--	--	--	--	--	--	--	<.1
Misc.	.1	.5	.2	.5	--	.5	.1	.3	.3	.9	.2	--	.2	--	--

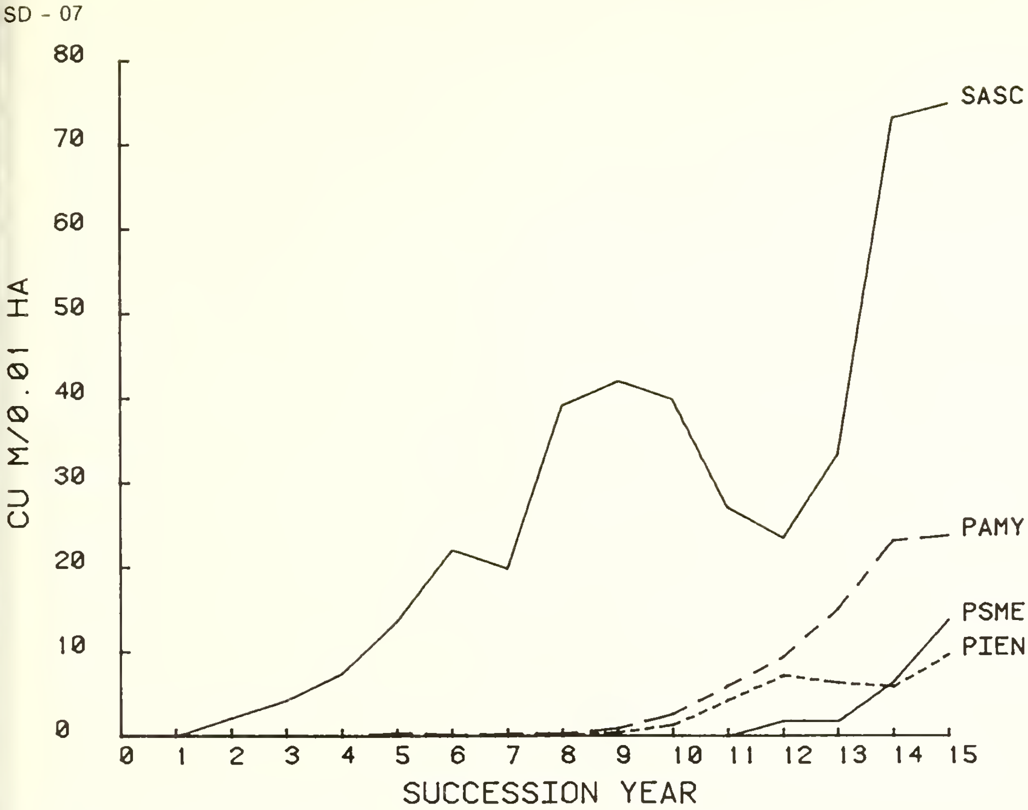


Figure 7-5.—Tree and shrub volume.

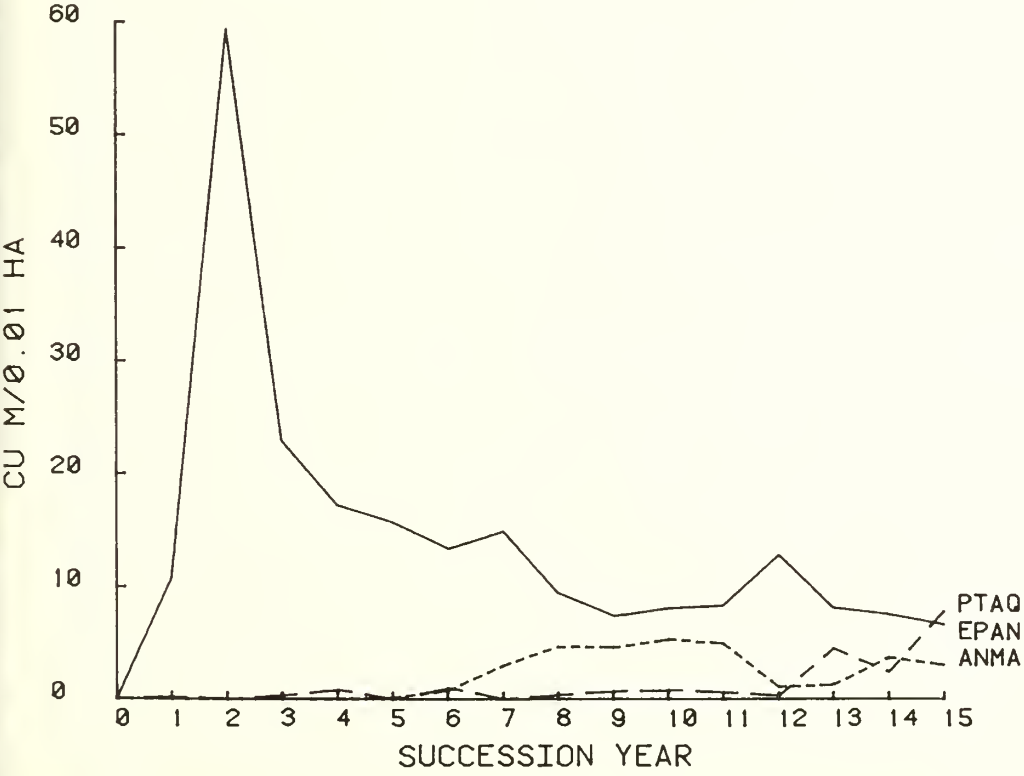


Figure 7-6.—Herb volume.

SUNDANCE BURN: 1802-16 Study Area SD-08

Site location and description: NW¼NW¼ sec. 8, T. 60 N., R. 2 W., BM; Elevation: 4,150 ft; Exposure: Northwest (Az. 320°); Slope: 50%

Forest cover type and tree size class: Western hemlock mature sawtimber, 40 to 70% canopy coverage

Reconstructed prefire forest stand:
Tree component: No prefire trees apparent
Shrub component: RULE 75%, SARA 25% (Shrub density: 1.6/0.01 ha);
Other species present: RUPA, VAME

Disturbance treatment:
Clearcut: Sawtimber logged prior to fire;
Wildfire: September 1, 1967 (1800 hrs); Succession year 1:1968;
Fire intensity: 11,300 Btu/sec/ft; Rate of spread: 2.5 mi/h;
Fire severity: R-N index: 3-M; Litter-duff: Consumed

Table 8-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 8-1

Life form component	Succession year														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1
Tree	--	--	--	--	--	--	--	--	--	--	1	1	3	4	
Shrub	1	16	15	19	25	31	44	64	--	50	52	50	55	76	8
Herb	44	48	37	32	30	14	22	21	--	29	29	34	29	46	4
Total veg.	45	64	51	50	55	45	66	85	--	79	82	86	87	126	13

Table 8-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 8-2

Life form component	Succession year														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1
Tree	--	--	--	--	--	--	--	--	--	--	0.2	0.4	1.3	6.7	1
Shrub	0.2	9.3	7.9	9.0	14.3	19.2	26.9	60.2	--	46.9	39.6	43.1	50.4	80.1	8
Herb	12.6	35.2	20.1	18.8	17.2	7.5	9.1	11.4	--	14.1	12.0	16.5	12.5	21.1	1
Total veg.	12.8	44.5	28.0	27.8	31.4	26.7	36.1	71.7	--	61.0	51.8	60.0	64.2	107.9	12

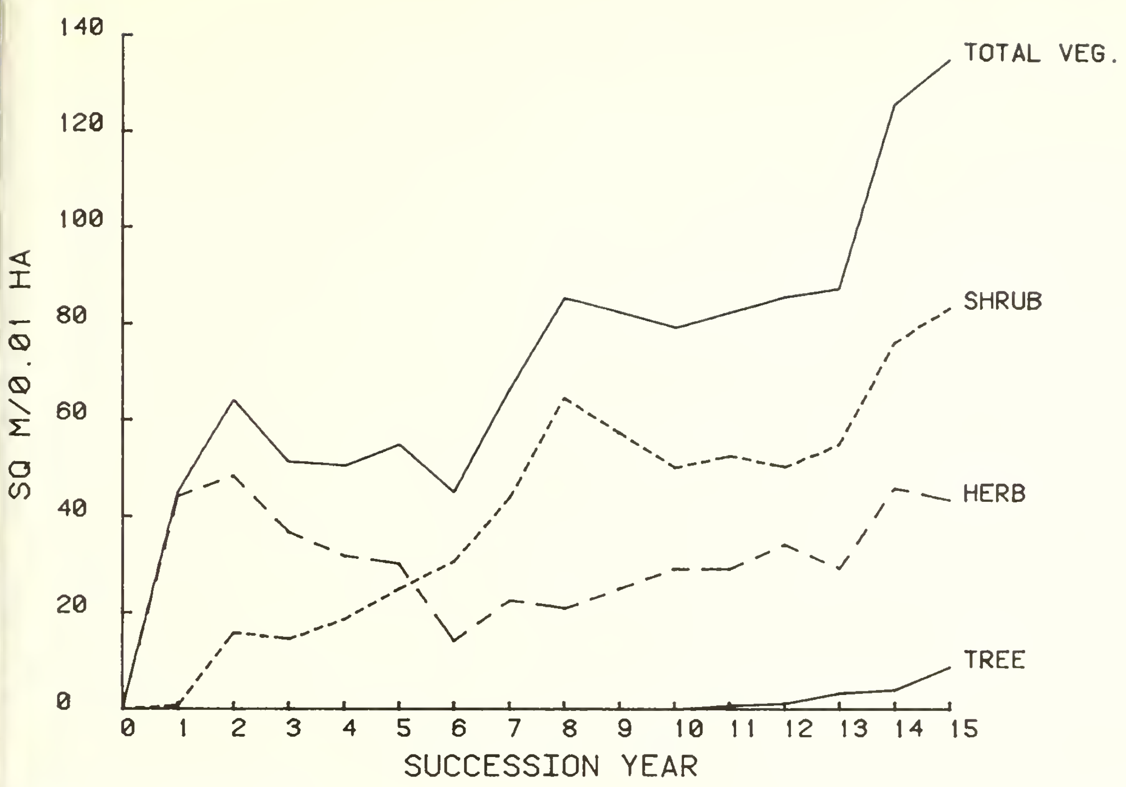


Figure 8-1.—Vegetative cover.

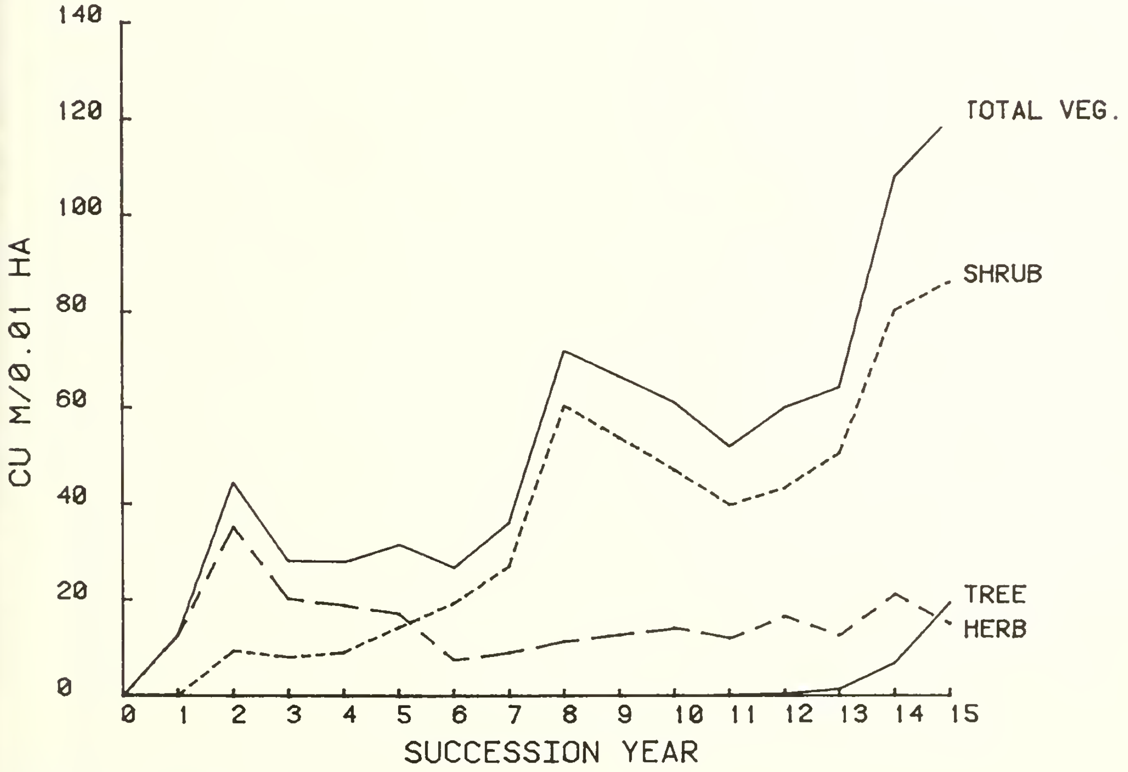


Figure 8-2.—Vegetative volume.

Table 8-3.--Cover development of tree and shrub components (m²/0.01 ha or %), fig. 8-3

Species	Succession year														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tree															
PIEN	--	--	--	--	--	--	--	--	--	--	1	1	2	1	1
POTRE	--	--	--	--	--	--	--	--	--	--	--	--	--	<1	--
PSME	--	--	--	--	--	--	--	--	--	--	--	<1	1	3	8
Shrub															
ALSI	--	--	--	--	--	--	--	--	--	--	--	--	1	1	2
PAMY	--	--	--	--	--	--	--	--	--	--	--	1	1	2	2
RUID	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--
RULE	--	4	1	1	1	2	1	1	--	<1	1	1	1	1	--
RUPA	1	2	2	2	3	6	8	14	--	14	16	12	13	22	27
SASC	--	7	11	15	21	22	33	48	--	36	36	37	40	51	52
SARA	--	2	1	1	--	--	1	1	--	--	--	--	--	--	--

Table 8-4.--Cover development of herb component (m²/0.01 ha or %), fig. 8-4

Species	Succession year														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
AGAL	--	--	--	--	--	--	--	--	--	--	1	1	1	1	1
ANMA	--	--	--	--	--	--	1	3	--	7	12	10	7	8	5
CAMI	--	--	--	--	--	--	--	--	--	--	--	1	--	8	9
CLUN	--	--	--	--	--	--	1	1	--	2	2	2	2	4	3
DIHO	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--
EPAN	42	47	33	28	27	12	19	12	--	16	11	12	13	16	9
HIAL	--	--	--	--	--	--	--	--	--	--	2	3	5	6	8
PTAQ	--	--	--	--	--	--	--	--	--	--	1	1	--	1	2
SOCA	--	--	--	--	--	--	--	--	--	--	--	--	--	1	1
TITRU	--	--	--	--	--	--	--	--	--	--	--	1	--	--	1
VIGL	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1
VIOR	--	--	--	--	--	--	--	--	--	--	--	2	--	2	2
Misc.	2	2	3	3	2	2	2	4	--	5	2	1	1	--	1

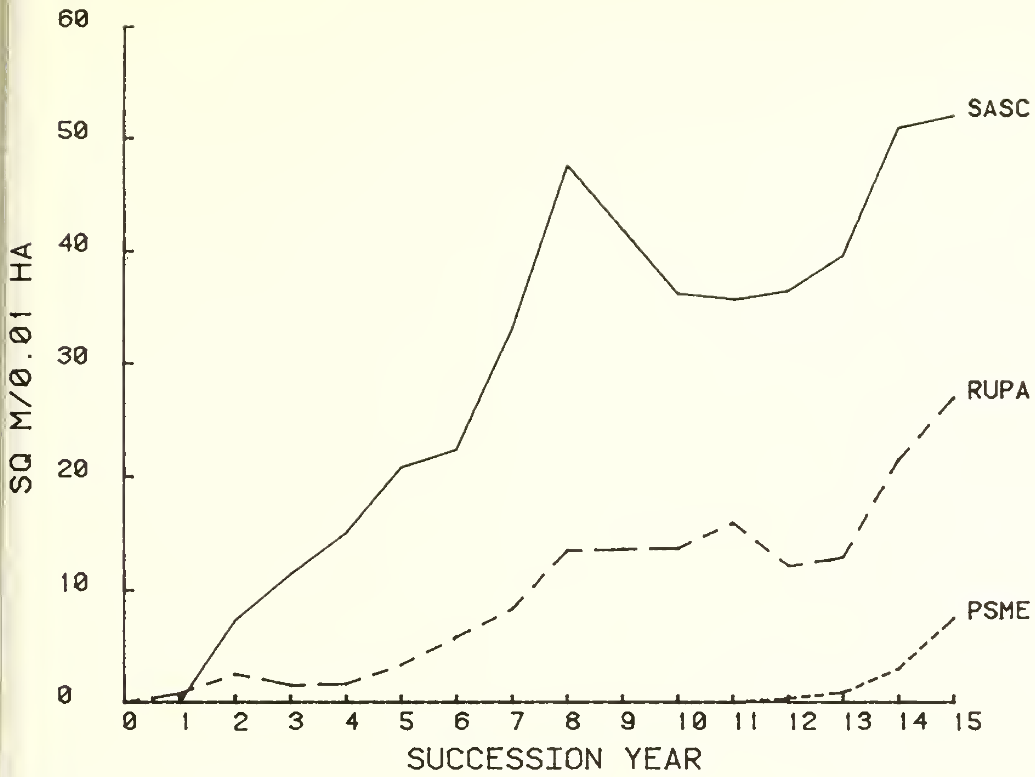


Figure 8-3.—Tree and shrub cover.

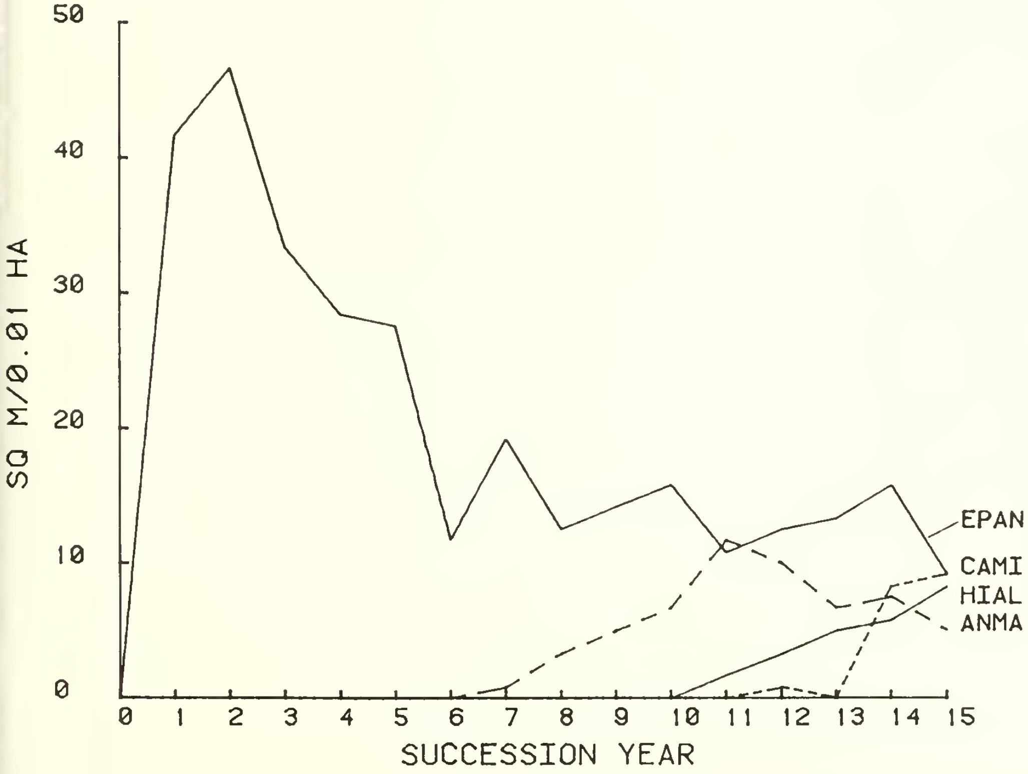


Figure 8-4.—Herb cover.

Table 8-5.--Volume development of tree and shrub components (m^3/0.01 ha), fig. 8-5

Species	Succession year 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tree															
PIEN	--	--	--	--	--	--	--	--	--	--	0.2	0.2	0.7	0.2	0.5
POTRE	--	--	--	--	--	--	--	--	--	--	--	--	--	.3	--
PSME	--	--	--	--	--	--	--	--	--	--	--	.2	.6	6.2	18.7
Shrub															
ALSI	--	--	--	--	--	--	--	--	--	--	--	--	1.4	3.7	5.7
PAMY	--	--	--	--	--	--	--	--	--	--	--	.2	.2	.6	1.0
RUID	--	--	--	--	--	--	--	0.9	--	--	--	--	--	--	--
RULE	--	1.9	0.4	0.3	0.3	0.8	0.6	.5	--	0.1	.4	.4	.4	.4	--
RUPA	0.2	.6	.7	.4	.9	1.2	2.1	6.3	--	5.9	6.3	4.9	5.0	9.1	13.8
SASC	--	4.4	5.3	6.4	13.0	17.2	22.3	50.6	--	40.9	32.9	37.5	43.4	66.3	65.5
SARA	--	2.4	1.5	2.0	--	--	2.0	2.0	--	--	--	--	--	--	--

Table 8-6.--Volume development of herb component (m^3/0.01 ha), fig. 8-6

Species	Succession year 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
AGAL	--	--	--	--	--	--	--	--	--	--	0.6	0.6	0.7	0.7	0.6
ANMA	--	--	--	--	--	--	0.6	2.5	--	2.1	5.1	4.3	2.7	3.3	2.2
CAMI	--	--	--	--	--	--	--	--	--	--	--	.4	--	5.0	3.3
CLUN	--	--	--	--	--	--	.1	.1	--	.1	.1	.2	.2	.4	.2
DIHO	--	--	--	--	--	--	--	--	--	--	--	.2	--	--	--
EPAN	12.2	34.8	19.5	18.1	16.6	7.0	8.4	7.7	--	11.2	5.7	9.5	7.8	10.2	6.2
HIAL	--	--	--	--	--	--	--	--	--	--	.1	.9	1.0	1.2	1.3
PTAQ	--	--	--	--	--	--	--	--	--	--	.2	.2	--	.2	.6
SOCA	--	--	--	--	--	--	--	--	--	--	--	--	--	.1	.2
TITRU	--	--	--	--	--	--	--	--	--	--	--	.1	--	--	--
VIGL	--	--	--	--	--	--	--	--	--	--	--	--	--	--	.1
VIOR	--	--	--	--	--	--	--	--	--	--	--	.1	--	.1	.1
Misc.	.4	.4	.6	.7	.6	.4	.1	1.2	--	.7	.3	.2	.1	--	.1

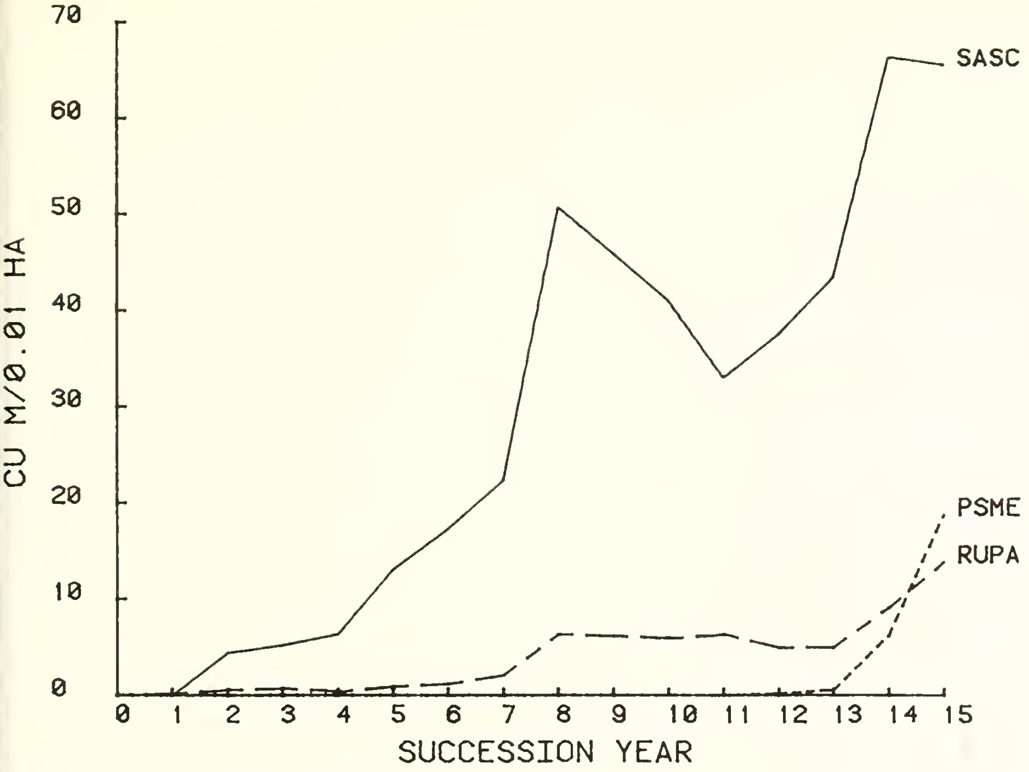


Figure 8-5.—Tree and shrub volume.

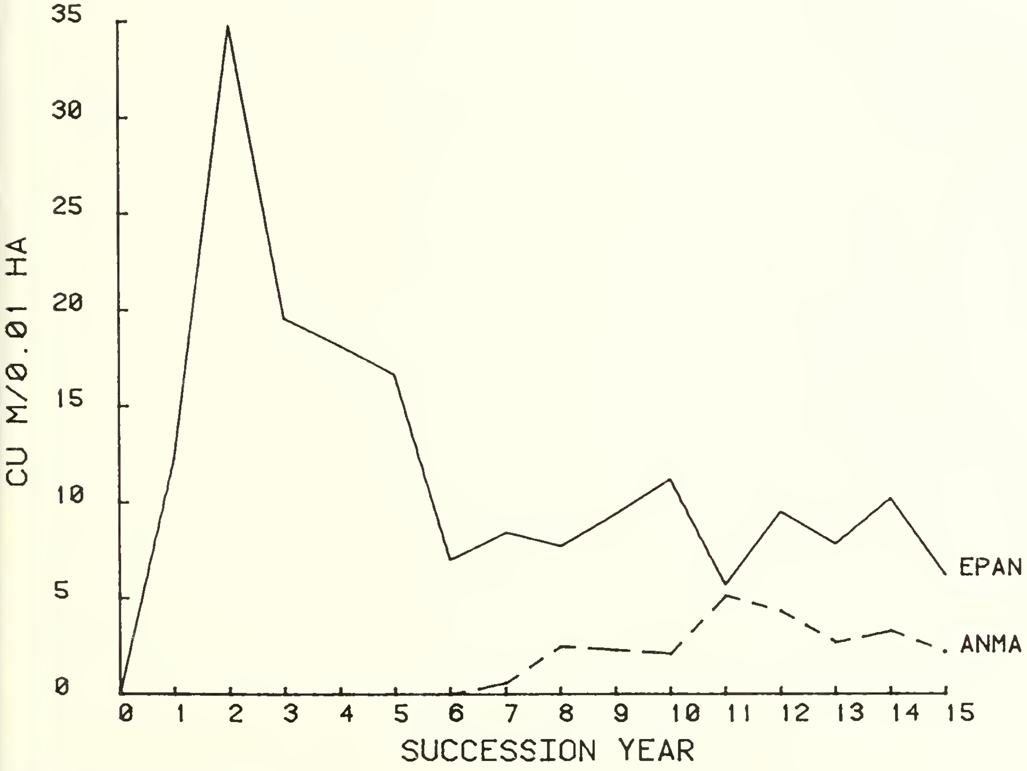


Figure 8-6.—Herb volume.

SUNDANCE BURN: 1802-16 Study Area SD-09

Site location and description: NW¼NW¼ sec. 8, T. 60 N., R. 2 W., BM; Elevation: 4,100 ft; Exposure: North (Az. 0°)
Slope: 45%

Forest cover type and tree size class: Western hemlock mature sawtimber, 40 to 70% canopy coverage

Reconstructed prefire forest stand:
Tree component: Conifer density: 3.2/0.01 ha; Average d.b.h.: 34.5 cm; Basal area: 3,335 cm²/0.01 ha
Shrub component: Species present: LOUT, OPHO, RULE, RUPA, VAME

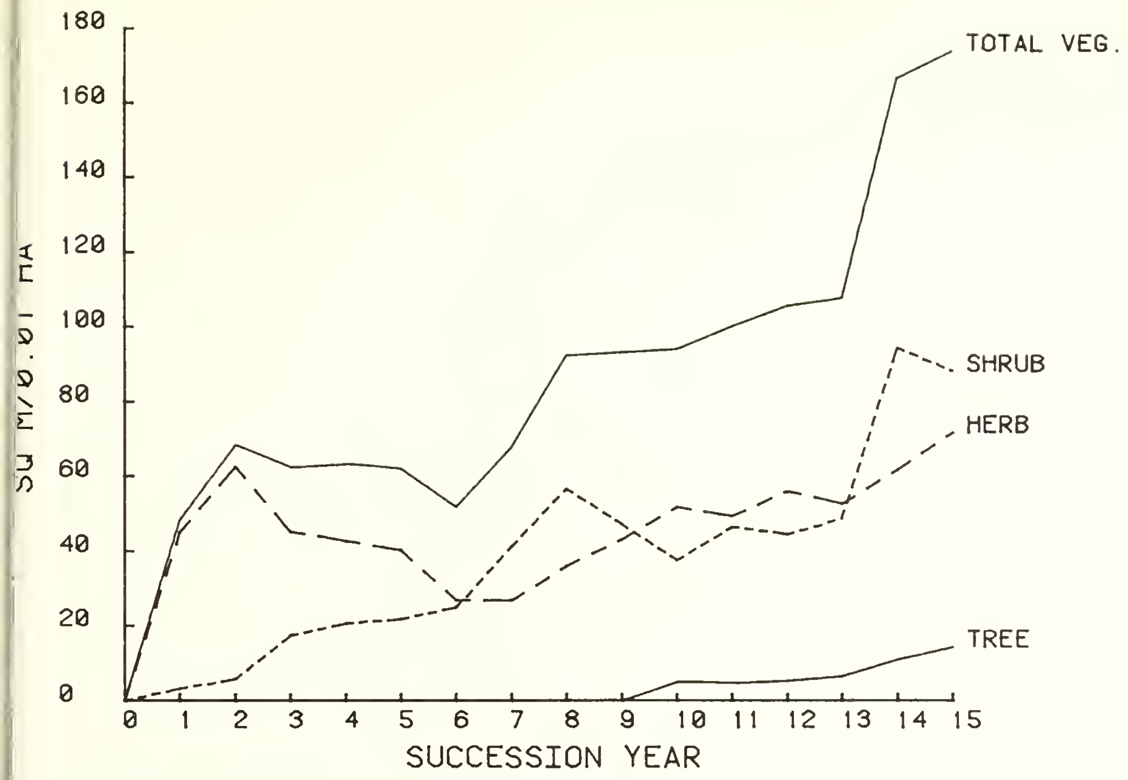
Disturbance treatment:
Wildfire: September 1, 1967 (1800 hrs); Succession year 1:1968;
Fire intensity: 11,300 Btu/sec/ft; Rate of spread: 2.5 mi/h;
Fire severity: R-N index: 5-M; Overstory crown foliage: Consumed; Litter-duff: Consumed

Table 9-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 9-1

Life form component	Succession year 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Tree	--	--	--	--	--	--	--	--	--	5	5	5	7	11
Shrub	3	6	17	21	22	25	41	57	--	37	46	44	49	94
Herb	45	62	45	42	40	27	27	36	--	52	49	56	52	62
Total veg.	48	68	62	63	62	52	68	92	--	94	100	106	108	167

Table 9-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 9-2

Life form component	Succession year 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Tree	--	--	--	--	--	--	--	--	--	9.5	9.6	11.8	10.8	29.6
Shrub	0.3	2.3	6.4	7.8	11.8	15.7	21.0	40.3	--	27.1	33.6	28.8	36.5	109.0
Herb	9.5	24.4	23.6	19.2	19.1	9.4	7.0	13.1	--	23.0	19.8	25.7	22.4	28.1
Total veg.	9.8	26.7	30.0	27.0	30.9	25.1	28.0	53.4	--	59.6	63.0	66.3	69.7	166.7



igure 9-1.—Vegetative cover.

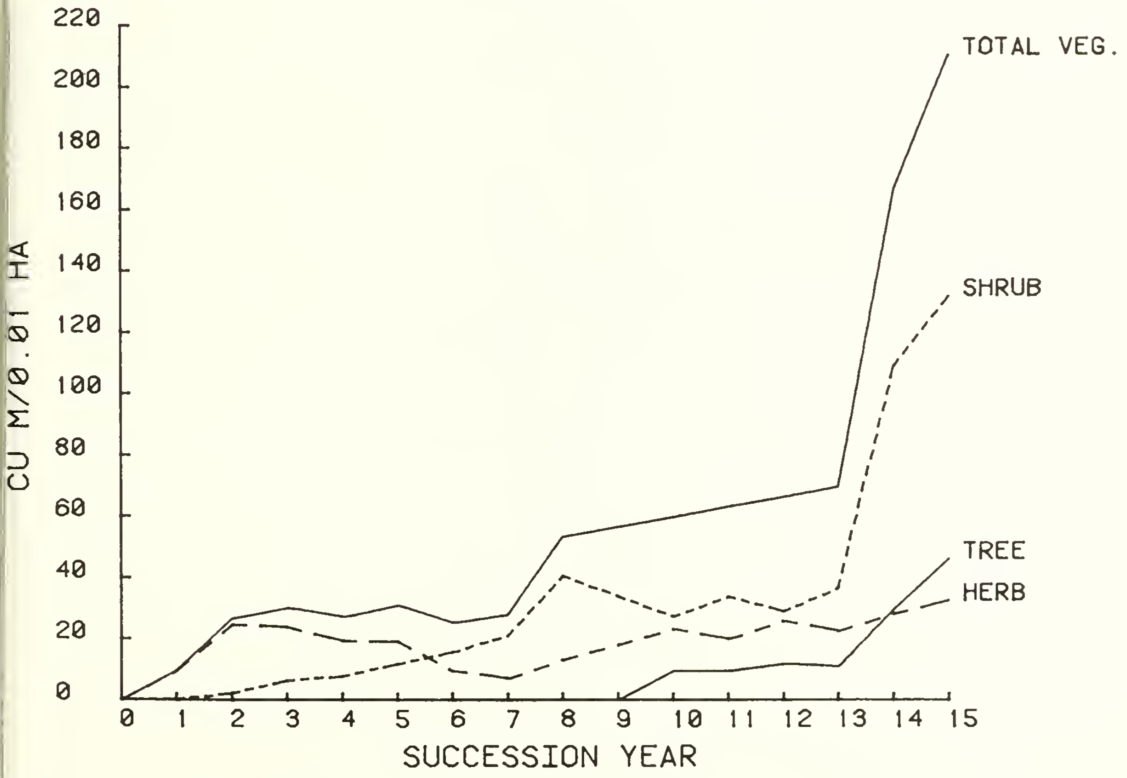


Figure 9-2.—Vegetative volume.

Table 9-3.--Cover development of tree and shrub components (m^2/0.01 ha or %), fig. 9-3

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tree															
POTRE	--	--	--	--	--	--	--	--	--	--	--	--	--	--	<1
PSME	--	--	--	--	--	--	--	--	--	5	5	5	7	11	14
Shrub															
ALSI	--	--	--	--	--	--	--	--	--	4	7	6	15	46	48
LOUT	--	--	--	--	--	--	--	1	--	1	1	--	--	2	2
PAMY	--	--	--	--	--	--	--	--	--	1	--	2	2	2	4
RULE	--	--	--	--	--	--	--	5	--	1	1	<1	--	--	--
RUPA	--	--	1	1	2	2	5	7	--	7	7	8	7	11	9
SASC	2	6	16	20	19	23	36	44	--	24	31	28	24	31	20
SARA	2	--	1	--	--	--	--	--	--	--	--	--	--	--	--
VAME	--	--	--	--	--	--	--	--	--	--	--	1	1	4	4

Table 9-4.--Cover development of herb component (m^2/0.01 ha or %), fig. 9-4

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
ADBI	--	--	--	--	--	--	--	--	--	--	--	--	1	2	--
ANMA	--	--	--	--	--	1	5	6	--	11	9	8	5	4	3
CAMI	--	--	--	--	--	--	--	--	--	2	3	8	6	9	7
CLUN	--	--	--	--	--	--	--	--	--	--	--	--	1	2	2
DAGL	--	--	--	--	--	--	1	--	--	1	--	--	1	1	1
EPAN	34	48	38	33	29	10	5	11	--	11	9	8	8	10	9
FEAR	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--
HIAL	--	--	--	--	--	--	--	--	--	--	--	1	3	2	3
PTAQ	6	9	2	5	9	12	12	15	--	19	23	28	27	31	42
TITRU	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1
TRRE	--	--	--	--	--	--	1	--	--	1	1	--	--	--	--
VIGL	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--
VIOR	--	--	--	--	--	--	--	--	--	--	--	--	--	1	2
Misc.	5	5	4	4	2	3	3	4	--	7	2	2	--	--	--

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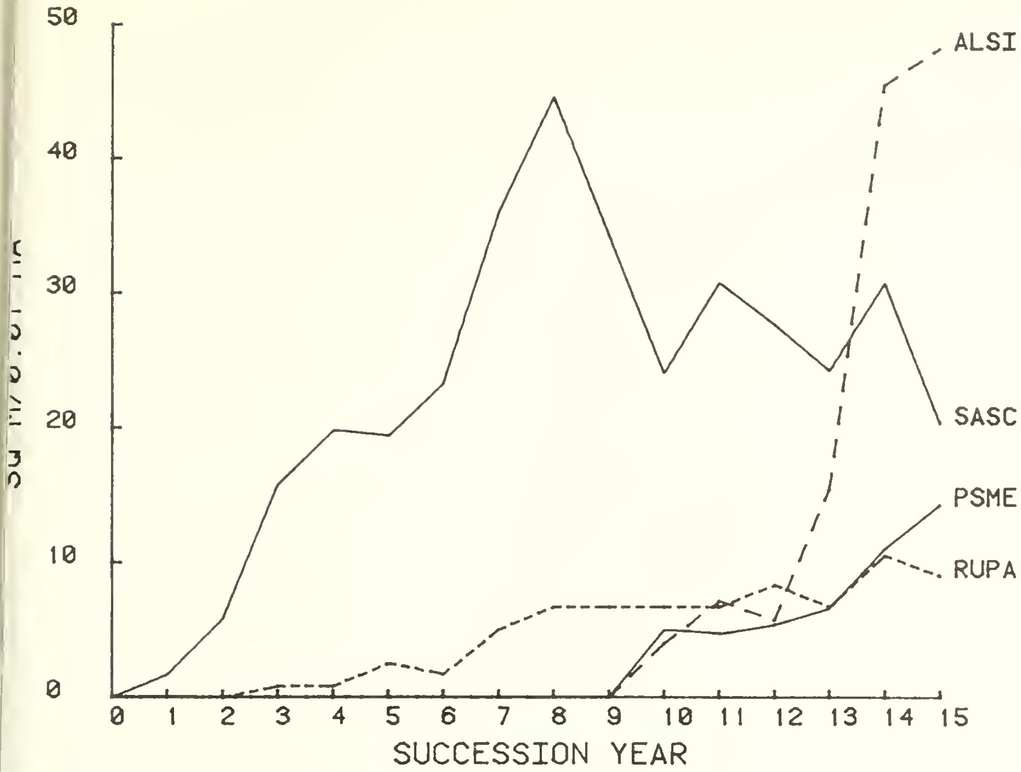


igure 9-3.—Tree and shrub cover.

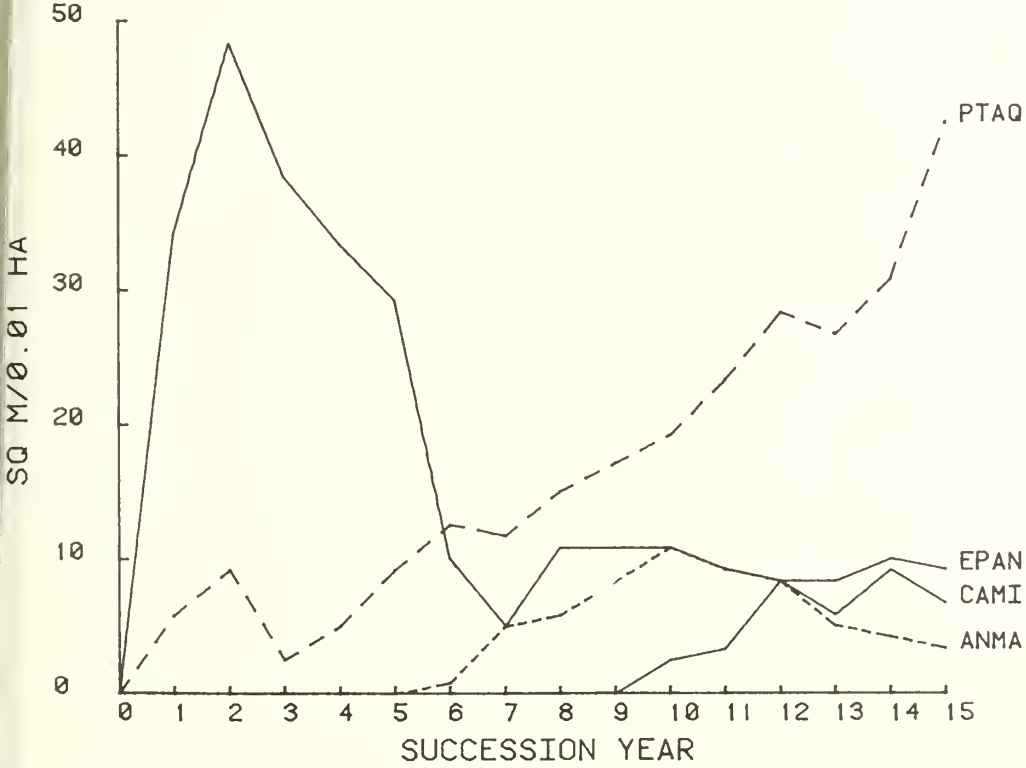


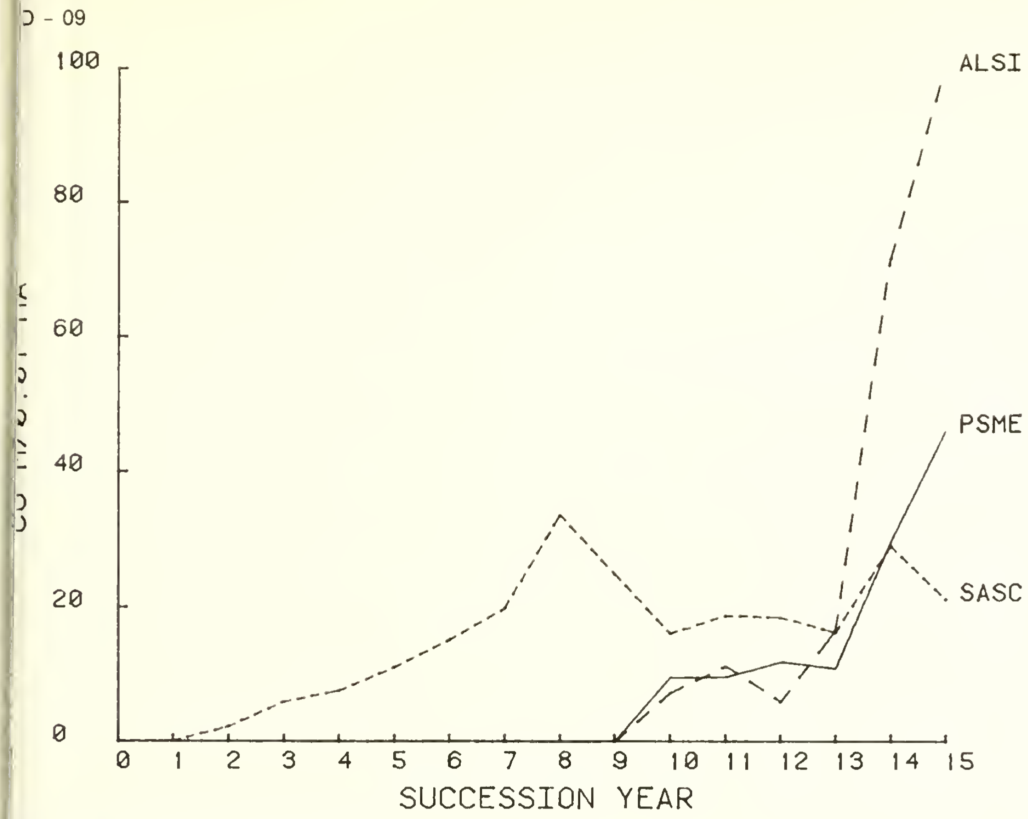
Figure 9-4.—Herb cover.

Table 9-5.--Volume development of tree and shrub components (m^3/0.01 ha), fig. 9-5

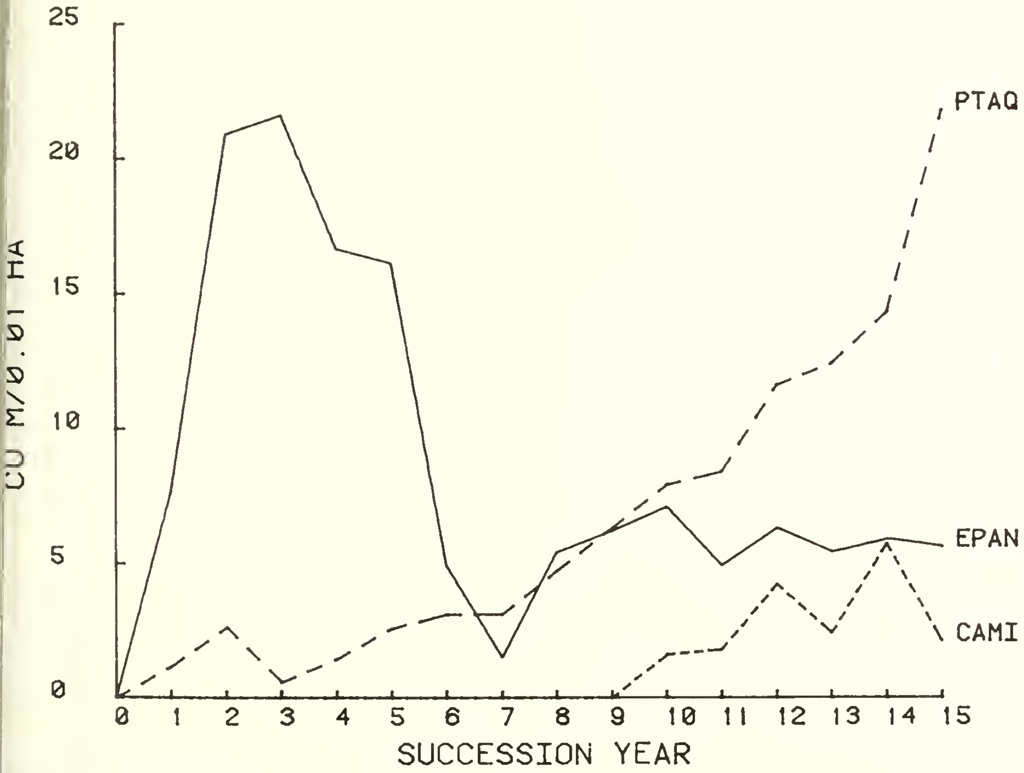
Species	Succession year														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tree															
POTRE	--	--	--	--	--	--	--	--	--	--	--	--	--	--	<0.
PSME	--	--	--	--	--	--	--	--	--	9.5	9.6	11.8	10.8	29.6	46.
Shrub															
ALSI	--	--	--	--	--	--	--	--	--	7.2	11.2	5.9	16.5	71.6	100.
LOUT	--	--	--	--	--	--	--	0.3	--	.5	.7	--	--	1.2	1.
PAMY	--	--	--	--	--	--	--	--	--	.4	--	.9	.9	1.2	2.
RULE	--	--	--	--	--	--	--	4.5	--	.7	.4	.1	--	--	--
RUPA	--	--	0.2	0.2	0.8	0.7	1.3	1.9	--	2.2	2.5	3.4	2.7	4.6	4.
SASC	0.2	2.3	6.0	7.6	11.1	15.1	19.8	33.5	--	16.1	18.7	18.4	16.2	29.0	21.
SARA	.1	--	.2	--	--	--	--	--	--	--	--	--	--	--	--
VAME	--	--	--	--	--	--	--	--	--	--	--	.2	.2	1.6	2.

Table 9-6.--Volume development of herb component (m^3/0.01 ha), fig. 9-6

Species	Succession year														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
ADBI	--	--	--	--	--	--	--	--	--	--	--	--	<0.1	0.3	--
ANMA	--	--	--	--	--	0.2	1.9	2.0	--	4.9	3.8	3.4	1.5	1.3	1.2
CAMI	--	--	--	--	--	--	--	--	--	1.6	1.8	4.2	2.4	5.7	2.1
CLUN	--	--	--	--	--	--	--	--	--	--	--	--	<1	.1	.3
DAGL	--	--	--	--	--	--	.2	--	--	.2	--	--	.3	.4	.7
EPAN	7.6	20.9	21.6	16.6	16.1	4.9	1.5	5.4	--	7.1	4.9	6.3	5.4	5.9	5.6
FEAR	--	--	--	--	--	--	--	--	--	--	.3	--	--	--	--
HIAL	--	--	--	--	--	--	--	--	--	--	--	<.1	.2	.1	.6
PTAQ	1.2	2.6	.6	1.4	2.6	3.1	3.1	4.7	--	7.9	8.4	11.6	12.4	14.3	21.8
TITRU	--	--	--	--	--	--	--	--	--	--	--	--	--	--	.2
TRRE	--	--	--	--	--	--	.1	--	--	.4	.2	--	--	--	--
VIGL	--	--	--	--	--	--	--	--	--	--	--	--	.1	--	--
VIOR	--	--	--	--	--	--	--	--	--	--	--	--	--	<.1	.1
Misc.	.7	.9	1.4	1.1	.4	1.3	.2	.9	--	.9	.4	.2	--	--	--



igure 9-5.—Tree and shrub volume.



igure 9-6.—Herb volume.

SUNDANCE BURN: 1802-16 Study Area SD-10

Site location and description: SW¼SW¼ sec. 8, T. 60 N., R. 2 W., BM; Elevation: 4,050 ft; Exposure: South (Az.
Slope: 30%

Forest cover type and tree size class: Western larch immature poletimber, 40 to 70% canopy coverage

Reconstructed prefire forest stand:
Tree component: Conifer density 22.8/0.01 ha; Average d.b.h.: 14.8 cm; Basal area: 4,993 cm^2/0.01 ha
Shrub component: Species present: PAMY, RULE, SASC, VAME

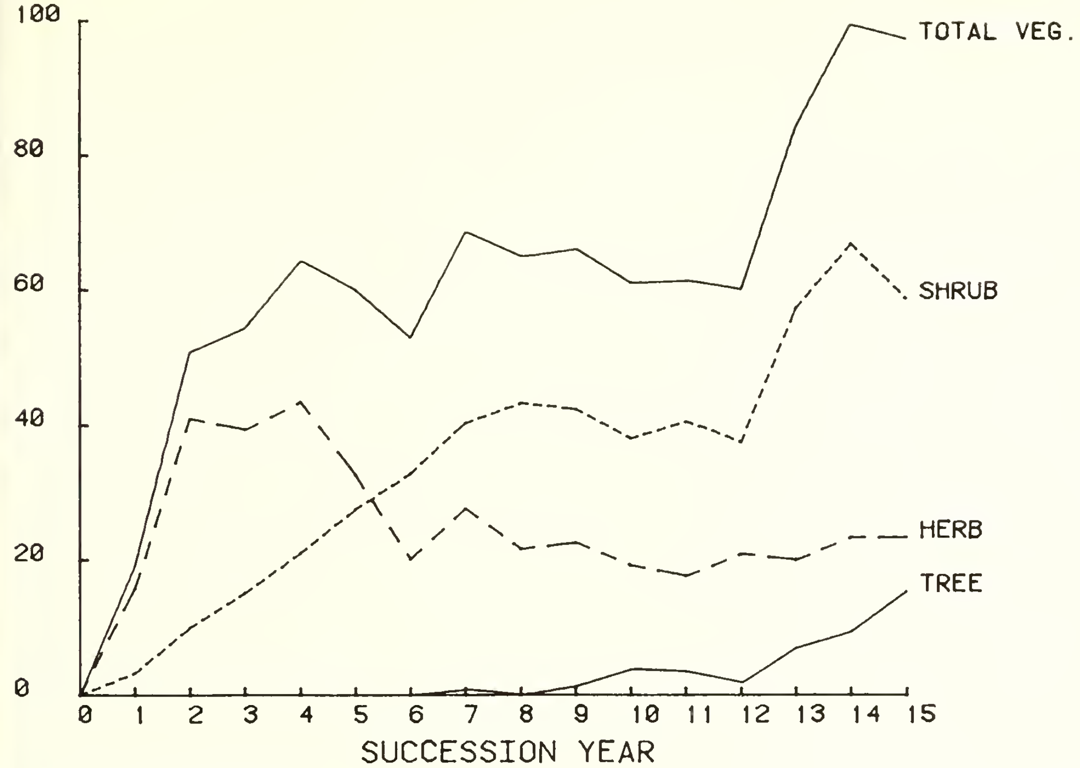
Disturbance treatment:
Wildfire: September 1, 1967 (1700-1800 hrs); Succession year 1:1968;
Fire intensity: 3,150 to 11,300 Btu/sec/ft; Rate of spread: 1 to 2.5 mi/h;
Fire severity: R-N index: 5-M; Overstory crown foliage: Consumed; Litter-duff: Consumed

Table 10-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 10-1

Life form component	Succession year													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Tree	--	--	--	--	--	--	1	--	1	4	3	2	7	9
Shrub	3	10	15	21	27	33	40	43	42	38	40	37	57	67
Herb	16	41	39	43	32	20	28	22	22	19	18	21	20	23
Total veg.	19	51	54	64	60	53	69	65	66	61	61	60	84	99

Table 10-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 10-2

Life form component	Succession year													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Tree	--	--	--	--	--	--	0.3	--	1.1	5.7	5.8	4.3	15.8	23.4
Shrub	0.3	5.6	9.9	15.8	23.8	32.6	28.8	40.4	38.7	35.4	34.0	30.6	48.3	73.6
Herb	4.3	21.8	20.9	28.2	16.2	7.9	10.7	9.4	8.5	7.0	5.7	8.9	9.4	10.5
Total veg.	4.6	27.5	30.8	43.9	39.9	40.4	39.7	49.9	48.4	48.1	45.5	43.8	73.5	107.5



igure 10-1.—Vegetative cover.

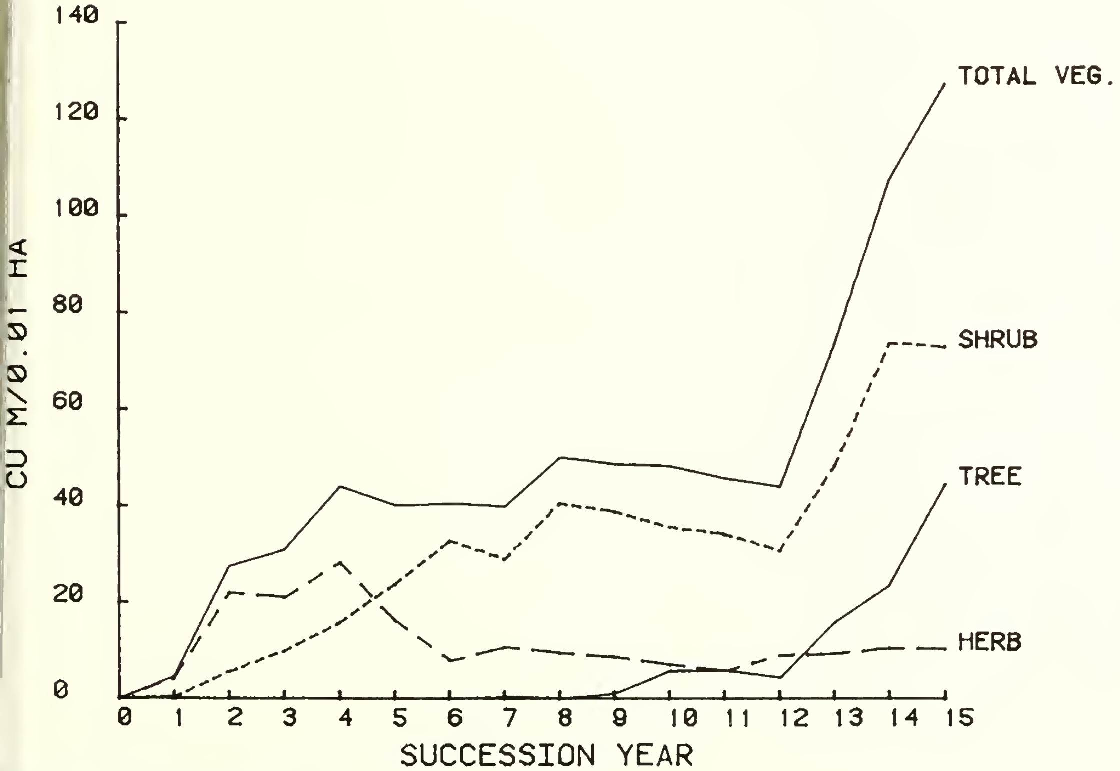


Figure 10-2.—Vegetative volume.

Table 10-3.--Cover development of tree and shrub components (m^2/0.01 ha or %), fig. 10-3

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tree															
POTRE	--	--	--	--	--	--	--	--	--	--	--	--	--	--	<1
PSME	--	--	--	--	--	--	1	--	1	4	3	2	7	9	15
Shrub															
ALSI	--	--	--	--	--	--	--	--	--	--	--	--	1	--	4
AMAL	--	--	--	--	--	--	--	--	--	--	--	1	2	3	--
PAMY	--	--	--	--	1	1	4	6	5	8	10	11	17	12	8
RULE	--	--	--	--	--	--	--	1	<1	--	1	<1	1	1	1
SASC	3	9	15	21	26	32	35	37	37	30	30	25	36	50	45
SARA	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--
VAME	--	--	--	--	--	--	1	--	--	--	--	--	--	1	1

Table 10-4.--Cover development of herb component (m^2/0.01 ha or %), fig. 10-4

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
AGAL	--	--	--	--	--	--	1	--	--	--	--	1	1	2	1
ANMA	--	--	--	--	--	2	7	8	10	2	2	2	2	2	2
APAN	--	--	--	--	--	--	--	--	--	--	--	--	3	1	--
CADE	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--
CARO	1	3	5	4	5	2	2	2	2	2	2	2	2	2	2
CLUN	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1
EPAN	15	36	33	38	27	13	8	8	9	11	10	12	7	10	8
ERAC	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--
FEAR	--	--	--	--	--	--	3	--	--	--	--	--	--	--	2
GNMI	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--
HIAL	--	--	--	--	--	--	--	--	--	1	2	2	2	2	2
ILRI	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--
PTAQ	--	--	--	--	--	--	1	--	1	--	1	2	1	1	2
SOCA	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--
VIOR	--	--	--	--	--	--	--	--	--	--	--	--	1	1	2
Misc.	--	2	1	1	--	2	2	4	1	3	1	1	--	2	2

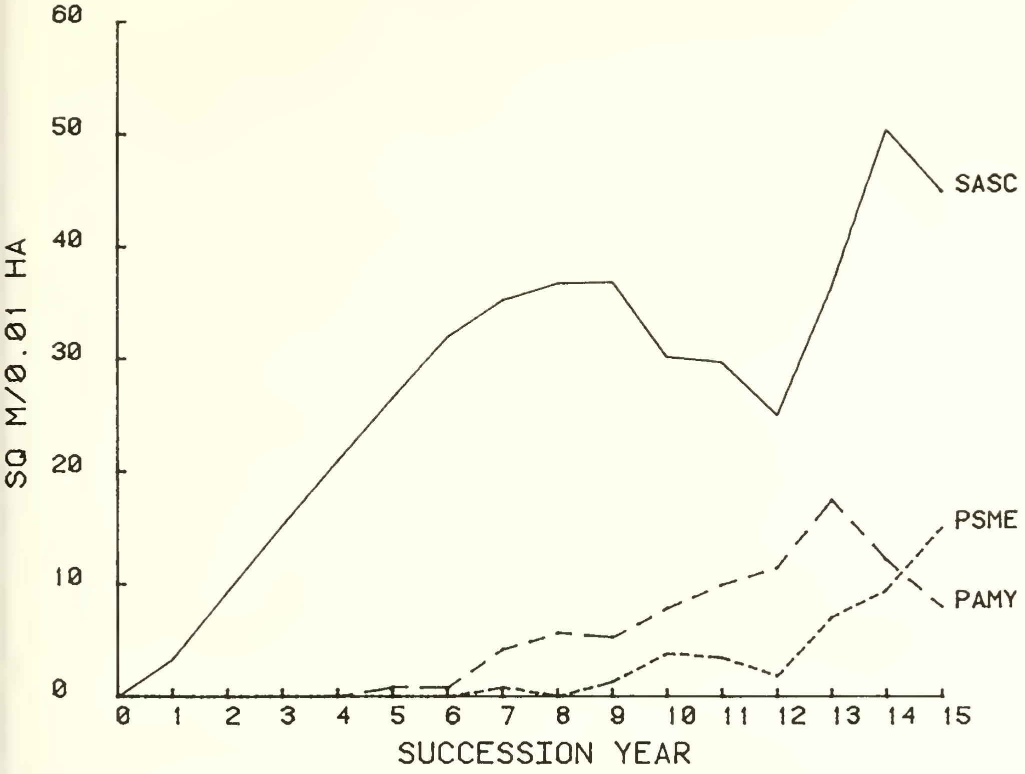


Figure 10-3.—Tree and shrub cover.

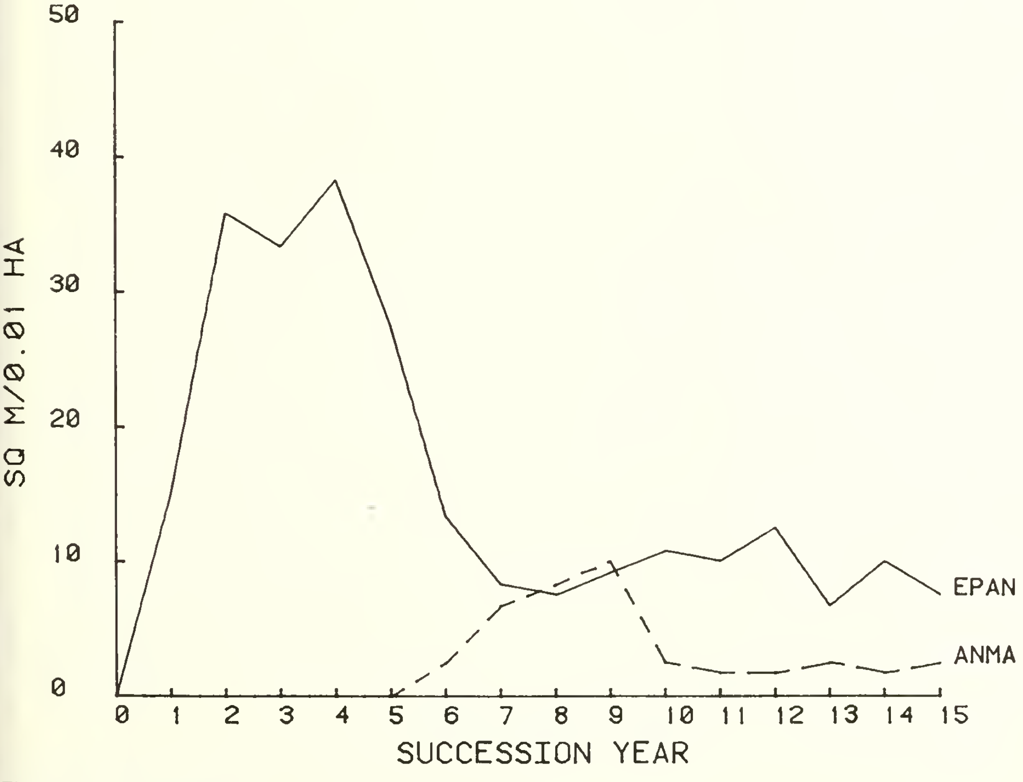


Figure 10-4.—Herb cover.

Table 10-5.--Volume development of tree and shrub components ($m^3/0.01$ ha), fig. 10-5

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tree															
POTRE	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.
PSME	--	--	--	--	--	--	0.3	--	1.1	5.7	5.8	4.3	15.8	23.4	44.
Shrub															
ALSI	--	--	--	--	--	--	--	--	--	--	--	--	1.1	--	8.
AMAL	--	--	--	--	--	--	--	--	--	--	--	.3	.9	2.5	--
PAMY	--	--	--	--	0.2	0.3	1.1	2.8	2.3	4.4	5.8	7.1	10.7	8.6	5.
RULE	--	--	--	--	--	--	--	.7	.1	--	.2	.2	.8	.5	.
SASC	0.3	5.1	9.9	15.8	23.6	32.3	27.6	37.0	36.3	31.1	28.1	23.0	34.9	61.9	57.
SARA	--	.6	--	--	--	--	--	--	--	--	--	--	--	--	--
VAME	--	--	--	--	--	--	.1	--	--	--	--	--	--	.1	.

Table 10-6.--Volume development of herb component ($m^3/0.01$ ha), fig. 10-6

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
AGAL	--	--	--	--	--	--	0.5	--	--	--	--	0.6	0.7	1.6	0.
ANMA	--	--	--	--	--	0.5	2.3	3.1	3.2	0.8	0.4	.6	.9	.7	1.
APAN	--	--	--	--	--	--	--	--	--	--	--	--	1.2	.3	--
CADE	--	--	--	--	--	--	.4	--	--	--	--	--	--	--	--
CARO	<0.1	0.5	0.8	0.7	0.7	.3	.5	.1	.2	.2	.2	.2	.1	.1	.
CLUN	--	--	--	--	--	--	--	--	--	--	--	--	--	--	<.
EPAN	4.2	20.9	19.9	27.3	15.5	6.8	4.2	5.2	4.8	5.5	4.7	7.0	4.9	6.3	5.
ERAC	--	--	--	--	--	--	--	--	--	--	--	--	.4	--	--
FEAR	--	--	--	--	--	--	1.0	--	--	--	--	--	--	--	.
GNMI	--	--	--	--	--	--	.4	--	--	--	--	--	--	--	--
HIAL	--	--	--	--	--	--	--	--	--	<.1	.2	.2	.9	.6	.
ILRI	--	--	--	--	--	--	.6	--	--	--	--	--	--	--	--
PTAQ	--	--	--	--	--	--	.3	--	.2	--	.2	.3	.2	.2	.
SOCA	--	--	--	--	--	--	--	--	--	--	--	--	--	.1	--
VIOR	--	--	--	--	--	--	--	--	--	--	--	--	<.1	<.1	.
Misc.	--	.4	.2	.2	--	.3	.5	1.0	.2	.4	.2	.1	--	.5	.

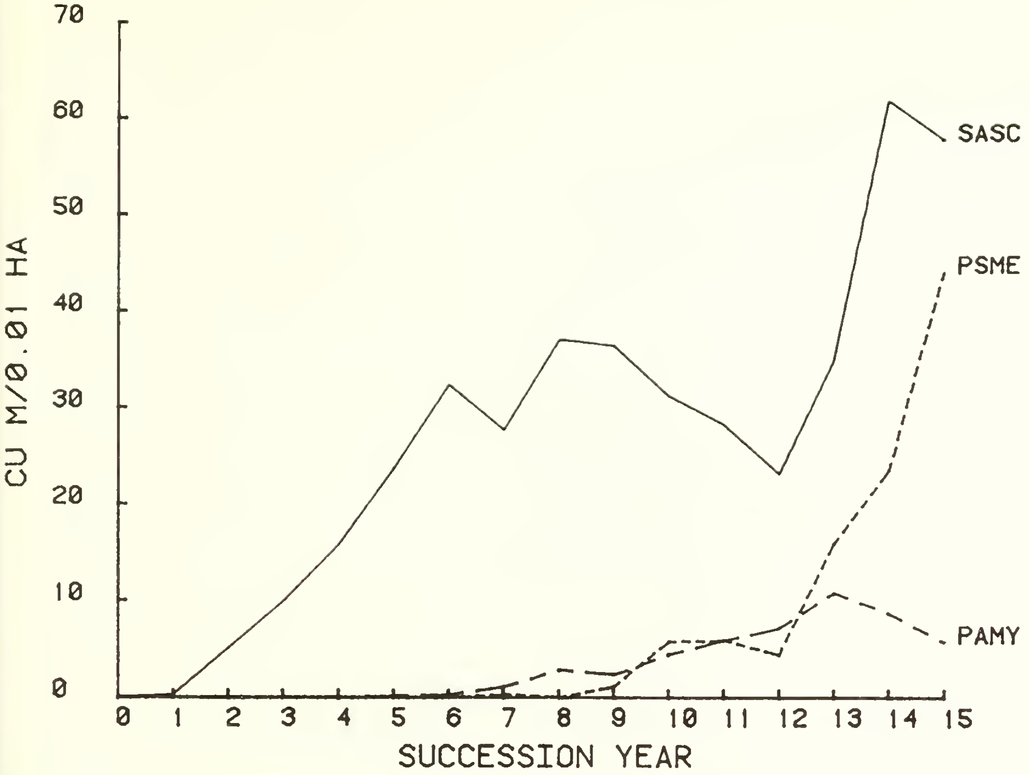


Figure 10-5.—Tree and shrub volume.

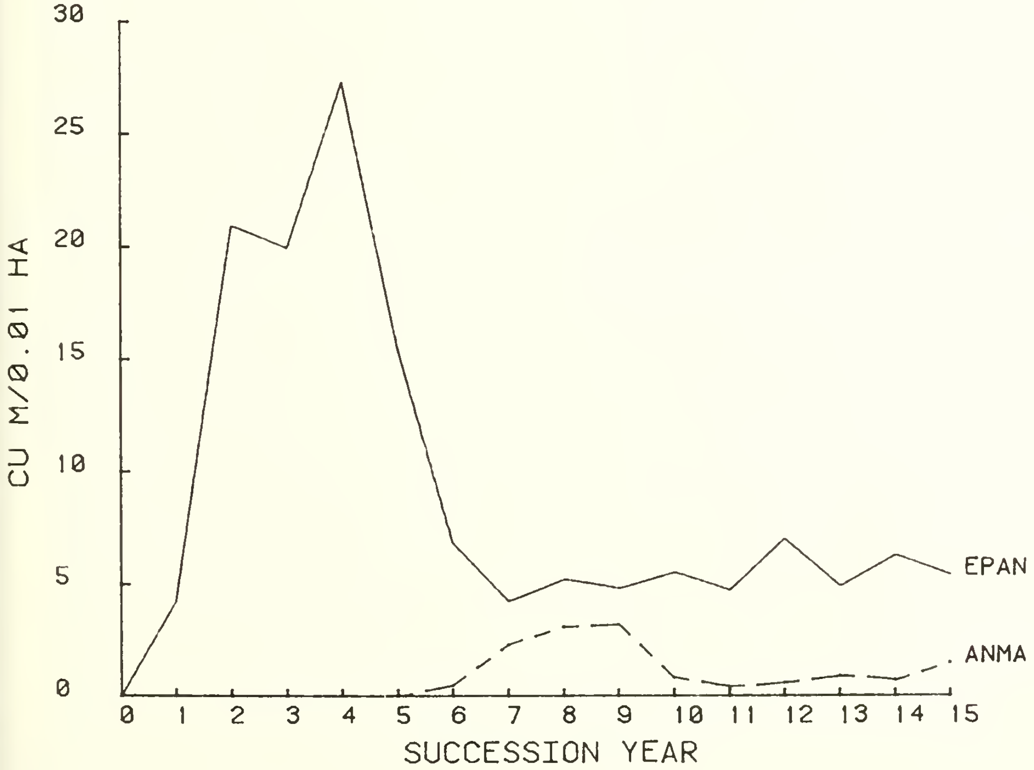


Figure 10-6.—Herb volume.

SUNDANCE BURN: 1802-16 Study Area SD-14

Site location and description: NW¼NE¼ sec. 9, T. 60 N., R. 2 W., BM; Elevation: 3,400 ft; Exposure: West (Az. 270
Slope: 40%

Forest cover type and tree size class: Douglas-fir immature poletimber, 70 through 100% crown coverage

Reconstructed prefire forest stand:
Tree component: Conifer density: 19.6/0.01 ha; Average d.b.h.: 15.9 cm; Basal area: 4,616 cm²/0.01 ha
Shrub component: Species present: AMAL, PAMY, ROGY, SASC

Disturbance treatment:
Wildfire: September 1, 1967 (1930 hrs); Succession year 1:1968;
Fire intensity: 3,400 to 22,500 Btu/sec/ft; Rate of spread: 1 to 6 mi/h;
Fire severity: R-N index: 5-M; Overstory crown foliage: Consumed; Litter-duff: Consumed

Table 11-1.--Successional development of vegetative cover (m²/0.01 ha or %), fig. 11-1

Life form component	Succession year													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Tree	--	--	--	--	--	--	--	--	--	--	--	2	1	2
Shrub	--	5	15	34	98	76	188	211	130	136	139	118	131	161
Herb	28	42	43	37	44	30	38	34	39	44	48	40	48	56
Total veg.	28	47	58	70	142	106	226	245	169	180	187	160	180	219

Table 11-2.--Successional development of vegetative volume (m³/0.01 ha), fig. 11-2

Life form component	Succession year													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Tree	--	--	--	--	--	--	--	--	--	--	--	4.2	2.7	5.4
Shrub	--	3.0	8.7	24.8	114.0	123.1	255.0	378.9	256.7	272.4	288.9	232.2	275.3	384.1
Herb	7.8	16.4	18.0	13.2	18.0	12.7	15.1	15.7	22.0	23.3	28.9	24.7	33.8	44.5
Total veg.	7.8	19.5	26.6	38.0	132.0	135.8	270.1	394.6	278.8	295.7	317.8	261.1	311.8	433.9

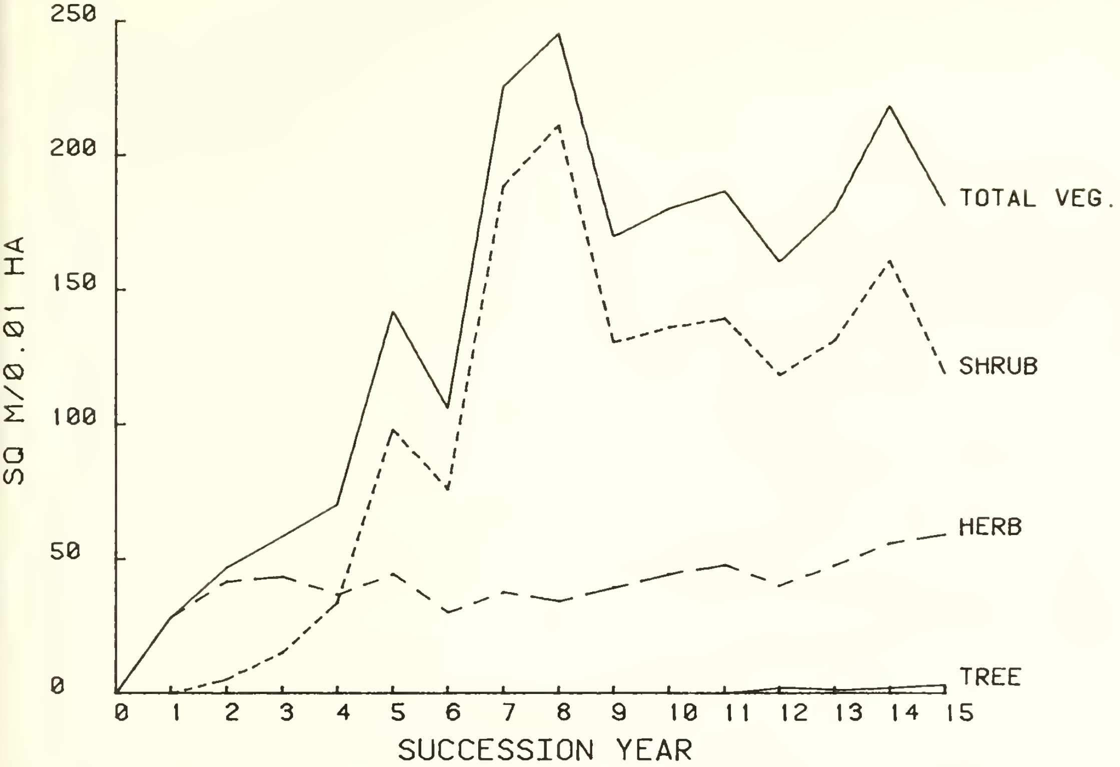


Figure 11-1.—Vegetative cover.

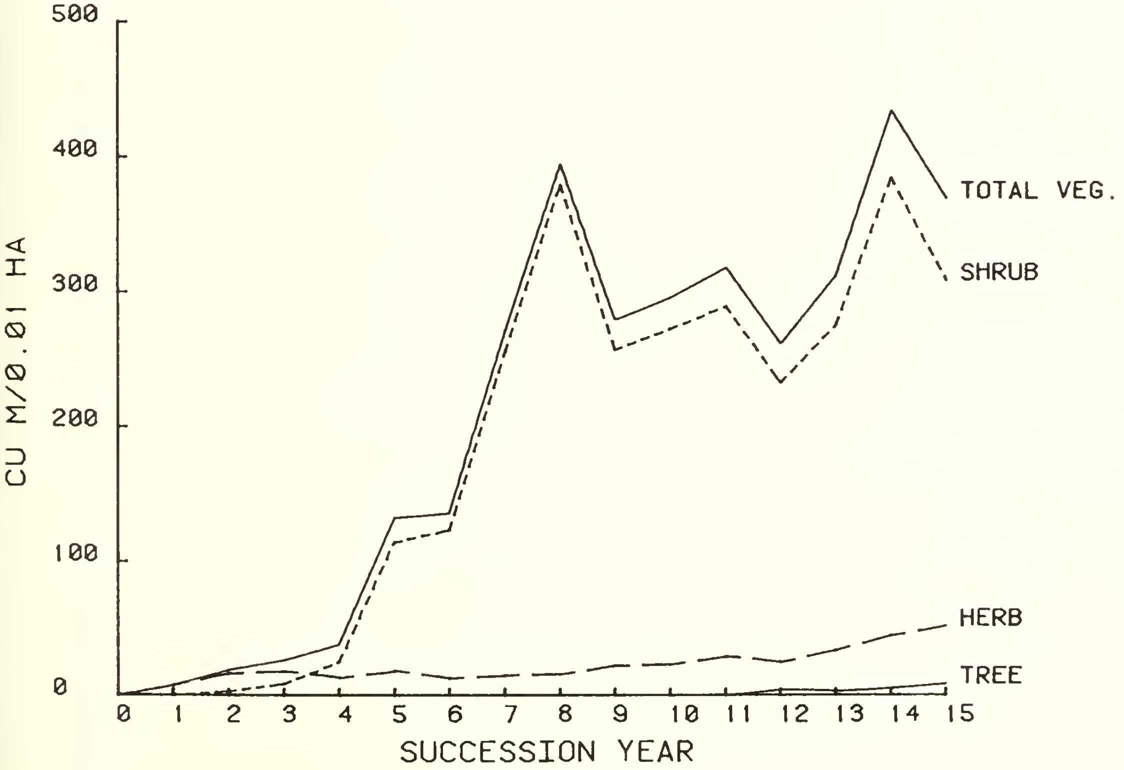


Figure 11-2.—Vegetative volume.

Table 11-3.--Cover development of tree and shrub components (m^2/0.01 ha or %), fig. 11-3

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tree															
POTRE	--	--	--	--	--	--	--	--	--	--	--	<1	--	--	<1
PSME	--	--	--	--	--	--	--	--	--	--	--	2	1	2	3
Shrub															
CESA	--	2	9	25	78	60	163	183	103	96	94	76	79	96	56
PAMY	--	--	--	--	--	--	--	--	1	1	3	2	10	6	7
ROGY	--	--	1	1	<1	1	2	6	7	8	13	5	6	9	3
RUPA	--	--	--	--	--	--	--	2	--	1	1	<1	1	3	--
SASC	--	3	6	8	19	15	24	21	19	30	29	35	36	47	52

Table 11-4.--Cover development of herb component (m^2/0.01 ha or %), fig. 11-4

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
ANMA	--	--	--	--	--	1	2	2	1	--	1	--	1	1	1
CARO	2	3	4	4	2	3	2	1	2	3	3	3	2	1	--
CLUN	--	--	--	--	--	--	--	--	--	--	1	1	1	2	2
EPAN	24	30	32	24	20	13	14	14	16	8	9	8	10	13	10
FEAR	--	--	--	--	--	--	1	--	1	2	2	2	2	2	2
HIAL	--	--	--	--	--	--	--	--	--	--	--	--	1	1	--
ILRI	--	--	--	--	--	--	--	--	--	1	--	--	3	1	1
PTAQ	1	7	5	7	18	9	18	16	18	28	31	25	28	35	42
Misc.	2	2	2	2	3	3	--	2	1	2	--	--	--	--	--

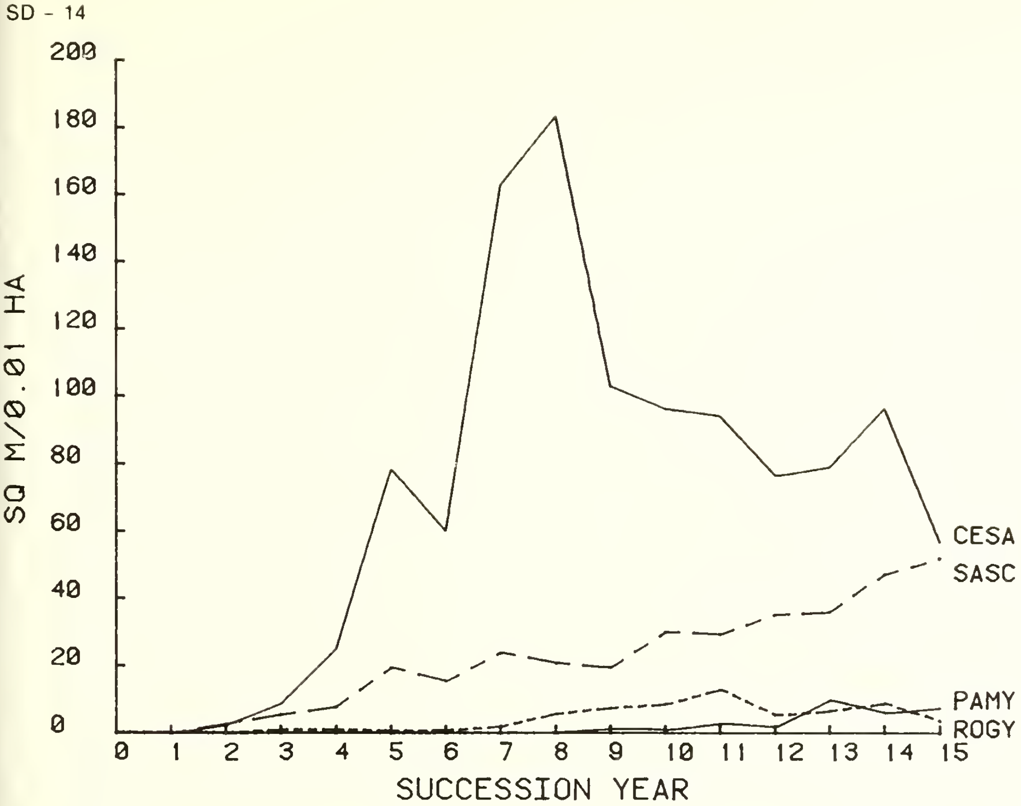


Figure 11-3.—Tree and shrub cover.

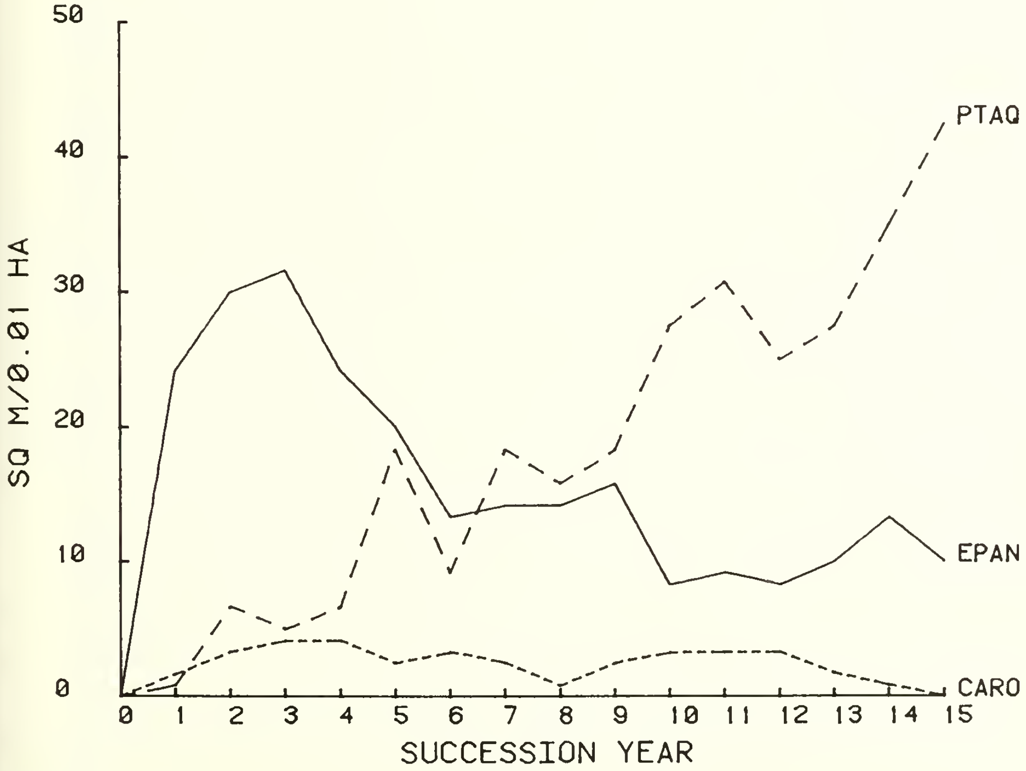


Figure 11-4.—Herb cover.

Table 11-5.--Volume development of tree and shrub components (m^3/0.01 ha), fig. 11-5

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tree															
POTRE	--	--	--	--	--	--	--	--	--	--	--	0.6	--	--	0.4
PSME	--	--	--	--	--	--	--	--	--	--	--	3.7	2.7	5.4	8.2
Shrub															
CESA	--	1.5	5.5	20.0	93.5	105.3	222.9	342.9	214.1	209.1	212.3	146.8	174.6	239.2	149.5
PAMY	--	--	--	--	--	--	--	--	.3	.1	1.0	.6	5.4	3.0	3.5
ROGY	--	--	.2	.1	.3	.5	.8	4.6	6.9	7.6	10.5	4.9	5.5	6.4	2.1
RUPA	--	--	--	--	--	--	--	1.0	--	.7	.5	.2	.4	2.6	--
SASC	--	1.6	2.9	4.7	20.2	17.2	31.3	30.3	35.5	54.9	64.5	79.7	89.4	132.8	153.0

Table 11-6.--Volume development of herb component (m^3/0.01 ha), fig. 11-6

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
ANMA	--	--	--	--	--	0.4	0.9	0.7	0.3	--	0.3	--	0.6	0.5	0.5
CARO	0.2	0.5	0.8	0.6	0.2	.5	.3	.1	.3	0.3	.3	0.4	.3	.1	--
CLUN	--	--	--	--	--	--	--	--	--	--	<.1	.1	<.1	.1	.1
EPAN	7.2	13.5	14.9	10.0	10.1	7.1	7.4	8.4	11.3	5.9	7.6	7.8	7.9	12.0	9.8
FEAR	--	--	--	--	--	--	.1	--	.2	.5	1.2	.7	1.2	1.8	.6
HIAL	--	--	--	--	--	--	--	--	--	--	--	--	<.1	.8	--
ILRI	--	--	--	--	--	--	--	--	--	.7	--	--	5.2	.9	1.5
PTAQ	.2	2.0	1.6	2.2	7.1	3.6	6.4	6.3	9.3	15.4	19.5	15.7	18.6	28.3	39.3
Misc.	.2	.4	.7	.4	.6	1.1	--	.3	.5	.4	--	--	--	--	--

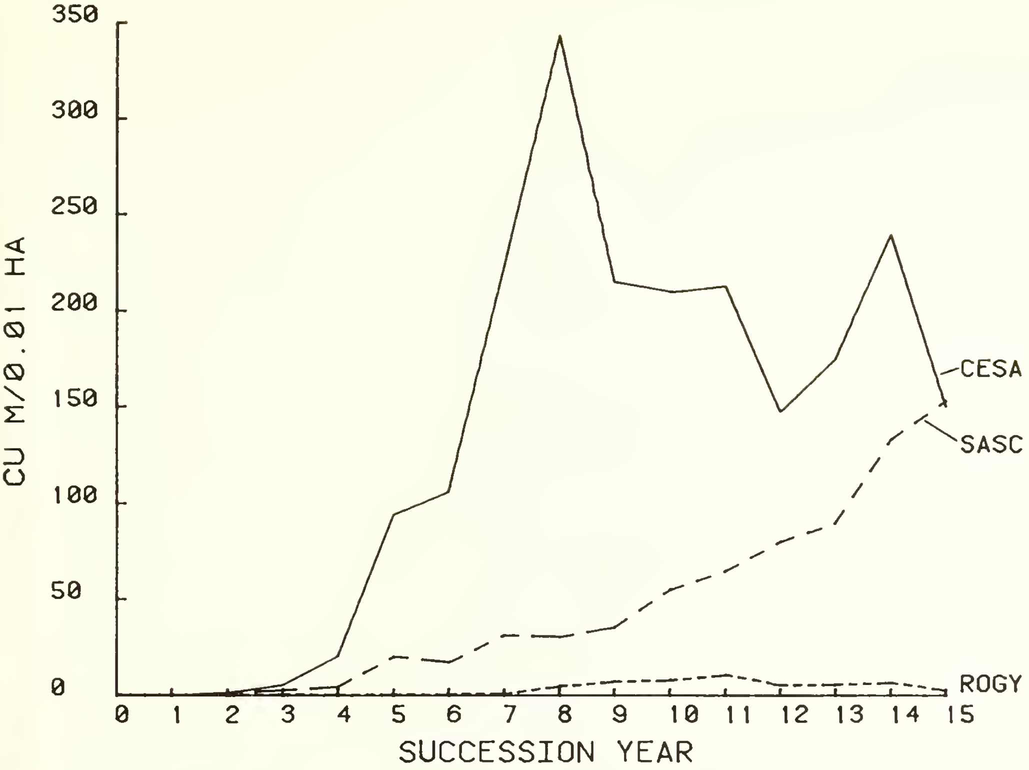


Figure 11-5.—Tree and shrub volume.

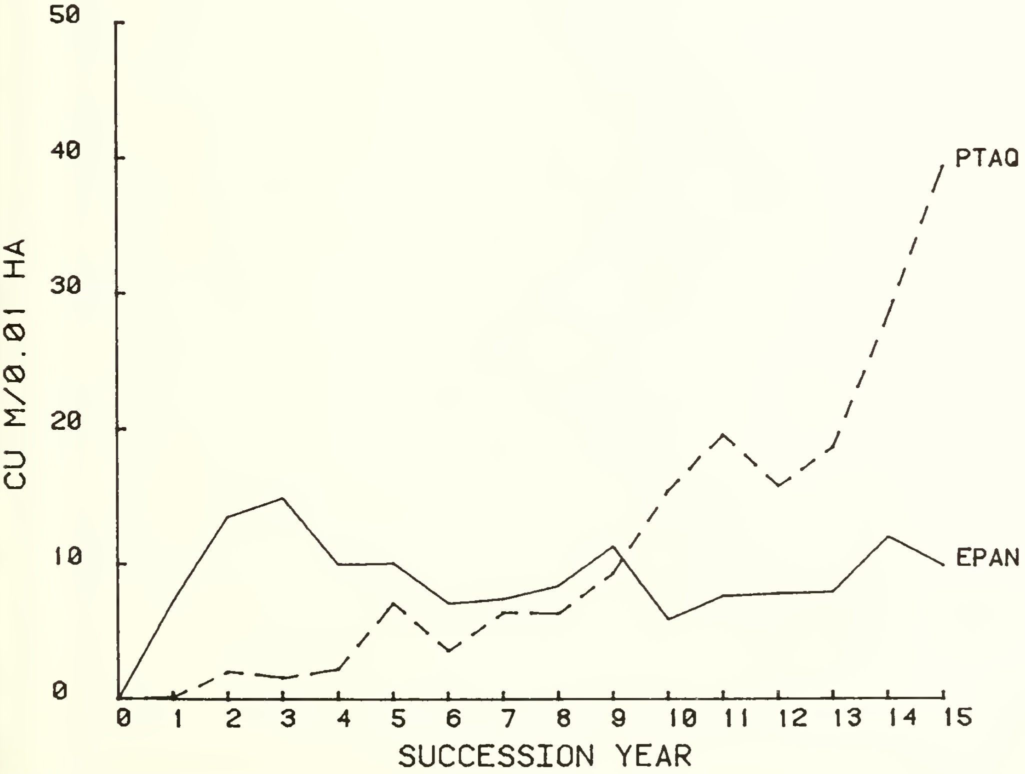


Figure 11-6.—Herb volume.

SUNDANCE BURN: 1802-16 Study Area SD-15

Site location and description: NE¼NE¼ sec. 9, T. 60 N., R. 2 W., BM; Elevation: 3,450 ft; Exposure: Southwest (Az. 225°); Slope: 30%

Forest cover type and tree size class: Douglas-fir immature poletimber, 70 through 100% crown coverage

Reconstructed prefire forest stand:
Tree component: Conifer density: 7.2/0.01 ha; Average d.b.h.: 12.6 cm; Basal area: 1,132 cm²/0.01 ha
Shrub component: ACGL 5%, AMAL 34%, ROGY 4%, SASC 41%, SYAL 16% (Shrub density: 17.6/0.01 ha);
Other species present: CESA, HODI, LOUT, PAMY, PREM, SOSC, SPBE

Disturbance treatment:
Wildfire: September 1, 1967 (1930 hrs); Succession year 1:1968;
Fire intensity: 3,400 to 22,500 Btu/sec/ft; Rate of spread: 1 to 6 mi/h;
Fire severity: R-N index: 5-M; Overstory crown foliage: Consumed; Litter-duff: Consumed

Table 12-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 12-1

Life form component	Succession year														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1
Tree	--	--	--	--	--	--	--	--	<1	1	2	2	2	2	
Shrub	12	28	38	57	88	92	122	114	108	90	103	74	115	129	15
Herb	32	36	35	38	36	20	26	28	36	32	28	28	18	28	2
Total veg.	43	63	73	96	124	112	147	142	144	123	133	103	135	159	18

Table 12-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 12-2

Life form component	Succession year														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1
Tree	--	--	--	--	--	--	--	--	0.1	0.4	1.5	1.8	1.8	3.1	
Shrub	8.4	23.3	32.5	50.3	102.5	105.4	134.0	145.1	132.6	113.7	126.1	87.3	146.6	185.2	23
Herb	5.1	10.6	10.3	10.8	8.5	4.8	7.0	5.9	11.3	8.3	6.5	6.6	5.3	7.5	
Total veg.	13.5	33.9	42.8	61.1	110.9	110.1	141.0	151.0	144.0	122.4	134.0	95.7	153.6	195.8	24

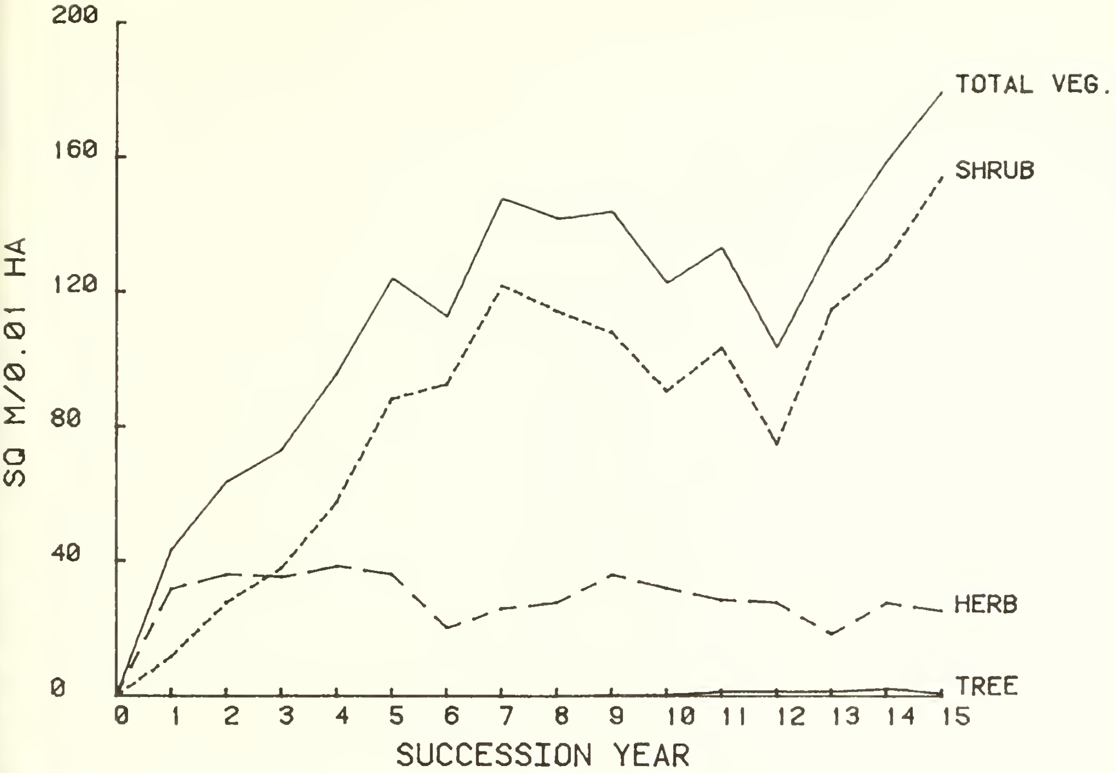


Figure 12-1.—Vegetative cover.

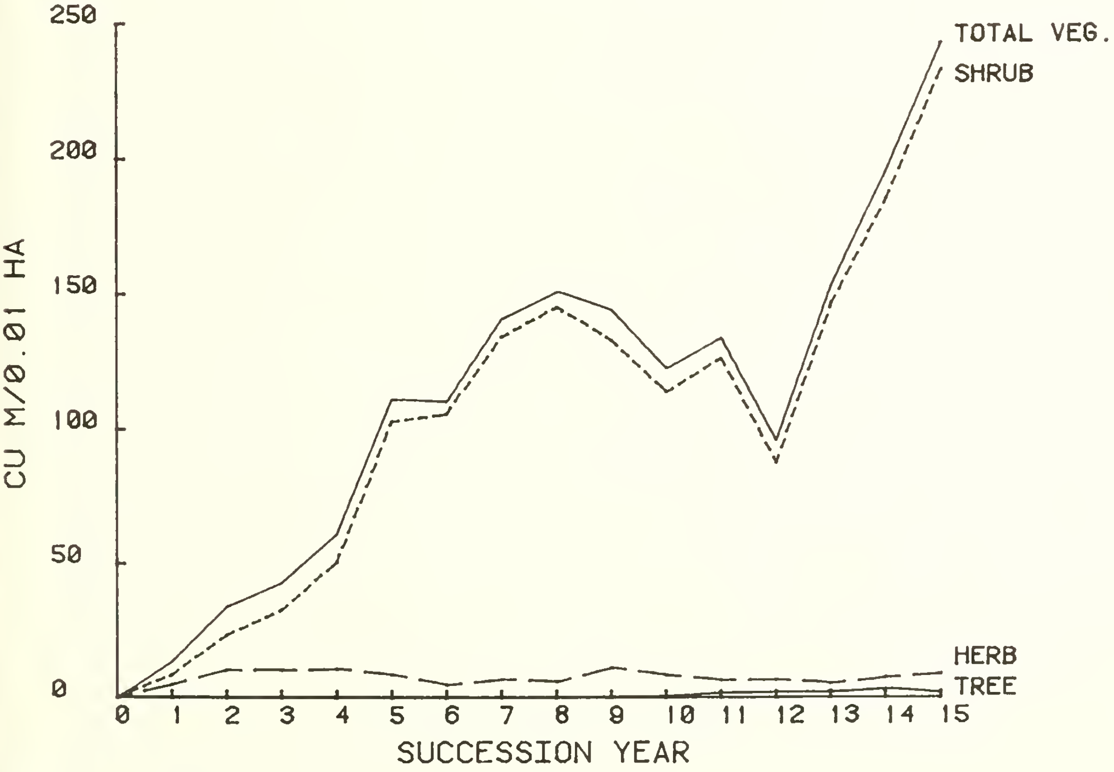


Figure 12-2.—Vegetative volume.

Table 12-3.--Cover development of tree and shrub components (m^2/0.01 ha or %), fig. 12-3

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tree															
PSME	--	--	--	--	--	--	--	--	<1	1	2	2	2	2	1
Shrub															
ACGL	1	2	2	2	4	5	2	2	2	2	2	1	1	4	5
AMAL	5	11	17	17	41	36	39	38	37	19	32	11	29	30	34
CESA	--	4	5	11	17	21	36	33	29	30	31	21	28	34	49
CEVE	--	--	--	--	--	--	<1	3	2	3	3	1	2	3	10
PAMY	--	--	1	2	2	2	4	4	6	6	8	14	12	17	19
ROGY	--	--	2	3	1	1	2	2	1	2	2	1	2	2	1
SASC	3	5	4	12	12	15	21	16	18	16	14	13	24	25	22
SPBE	2	6	7	10	11	11	11	12	13	13	11	14	17	13	13
SYAL	--	--	<1	--	--	<1	2	2	--	1	1	--	1	1	<1

Table 12-4.--Cover development of herb component (m^2/0.01 ha or %), fig. 12-4

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
CARU	--	2	2	5	6	4	7	5	9	9	12	11	7	12	13
CAGE	--	1	--	--	--	--	--	1	2	2	4	3	3	5	4
CARO	2	7	3	5	9	4	8	8	8	2	5	3	3	2	3
EPAN	12	18	22	16	10	3	2	2	4	2	1	1	1	1	1
EPPA	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--
GEBI	11	--	--	--	--	--	--	--	--	--	--	--	--	--	--
ILRI	--	1	1	1	1	1	2	1	2	2	1	1	1	1	1
LUAR	--	--	2	5	5	5	4	6	8	8	5	8	2	2	2
Misc.	8	8	4	7	5	2	3	6	4	6	1	--	--	5	--

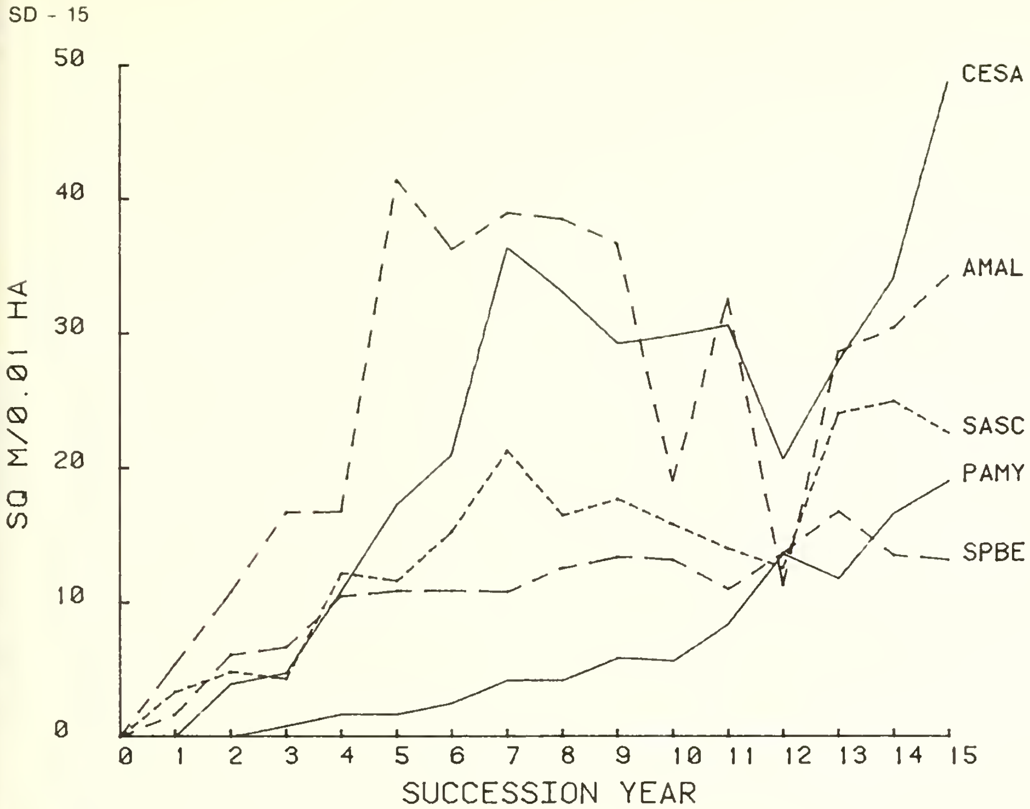


Figure 12-3.—Tree and shrub cover.

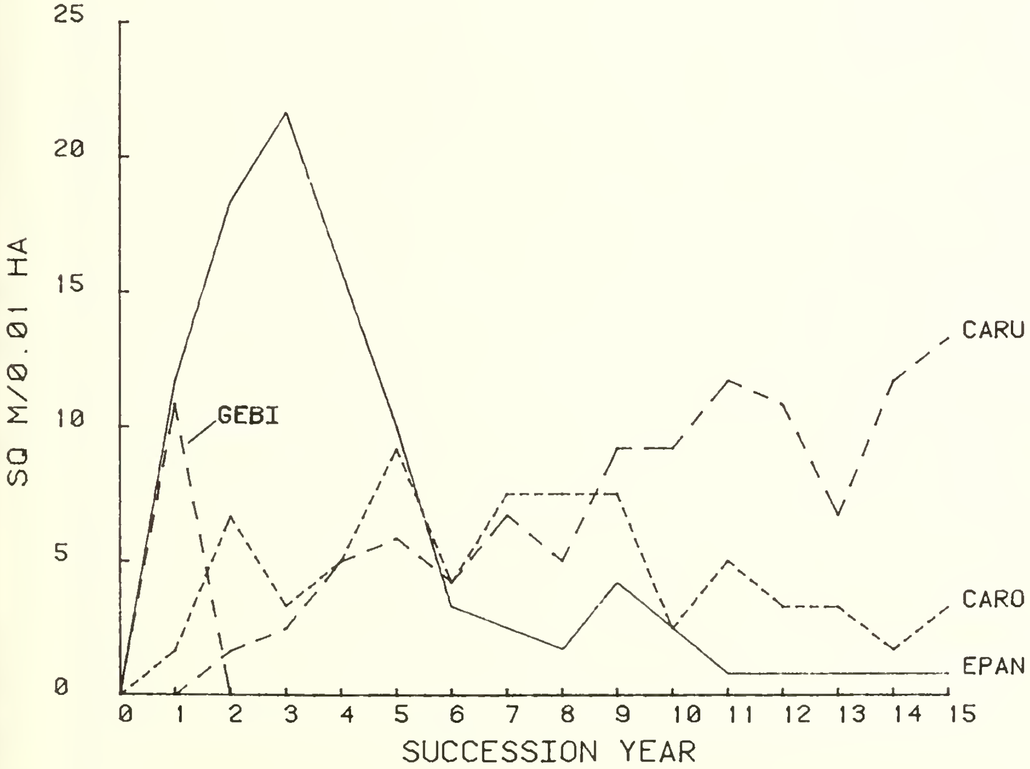


Figure 12-4.—Herb cover.

Table 12-5.--Volume development of tree and shrub components (m^3/0.01 ha), fig. 12-5

Species	Succession year 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tree															
PSME	--	--	--	--	--	--	--	--	0.1	0.4	1.5	1.8	1.8	3.1	1.3
Shrub															
ACGL	0.7	1.4	2.2	2.0	4.6	5.5	2.2	3.8	3.8	2.8	3.4	2.8	1.7	8.9	14.1
AMAL	4.1	12.1	19.9	18.9	54.8	42.7	45.4	48.2	49.3	25.0	40.3	17.7	41.4	40.4	50.5
CESA	--	1.8	2.1	9.6	22.3	32.3	43.4	56.6	42.7	46.9	46.9	30.9	36.7	62.1	83.4
CEVE	--	--	--	--	--	--	.2	3.0	1.7	2.8	3.4	.6	1.9	3.3	11.3
PAMY	--	--	.1	.2	.2	.2	.9	.9	1.5	1.6	1.8	4.6	4.6	6.3	8.8
ROGY	--	--	.5	.8	.4	.6	1.0	.5	.8	1.6	.5	.3	.8	.4	.3
SASC	3.3	6.1	5.8	15.9	17.0	21.0	29.6	27.4	28.5	28.1	25.4	26.1	53.1	59.1	60.8
SPBE	.3	1.9	1.7	2.9	3.2	2.8	3.9	3.4	4.4	4.4	3.8	4.4	5.5	4.1	3.9
SYAL	--	--	.2	--	--	.2	.9	1.3	--	.5	.3	--	.8	.7	.2

Table 12-6.--Volume development of herb component (m^3/0.01 ha), fig. 12-6

Species	Succession year 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
CARU	--	0.5	0.9	1.2	1.3	1.2	2.3	1.1	2.5	2.4	2.8	2.8	1.8	4.1	6.1
CAGE	--	.1	--	--	--	--	--	.2	.4	.5	.6	.5	.7	1.1	.9
CARO	0.1	.6	.4	.5	.9	.4	1.3	.9	1.2	.3	.8	.4	.7	.2	.4
EPAN	3.1	8.0	7.7	6.2	4.0	1.4	1.1	.5	2.9	1.1	.4	.5	.4	.7	.4
EPPA	--	--	--	--	--	--	--	--	--	--	--	--	.4	--	--
GEBI	.9	--	--	--	--	--	--	--	--	--	--	--	--	--	--
ILRI	--	.1	.2	.2	.3	.4	.7	.5	1.7	1.5	.7	.5	.4	.6	.4
LUAR	--	--	.5	1.4	1.2	1.0	1.2	1.6	2.1	1.5	1.1	1.9	.8	.7	.8
Misc.	1.0	1.2	.7	1.2	.7	.3	.5	1.1	.6	.9	.2	--	--	.2	--

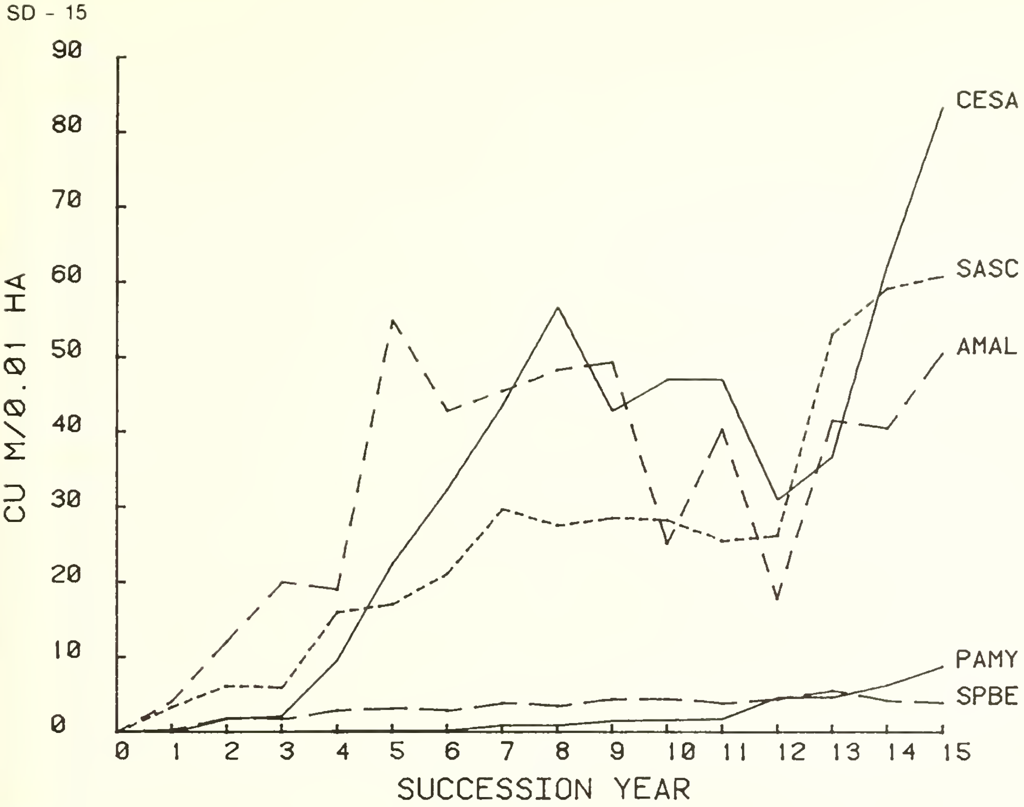


Figure 12-5.—Tree and shrub volume.

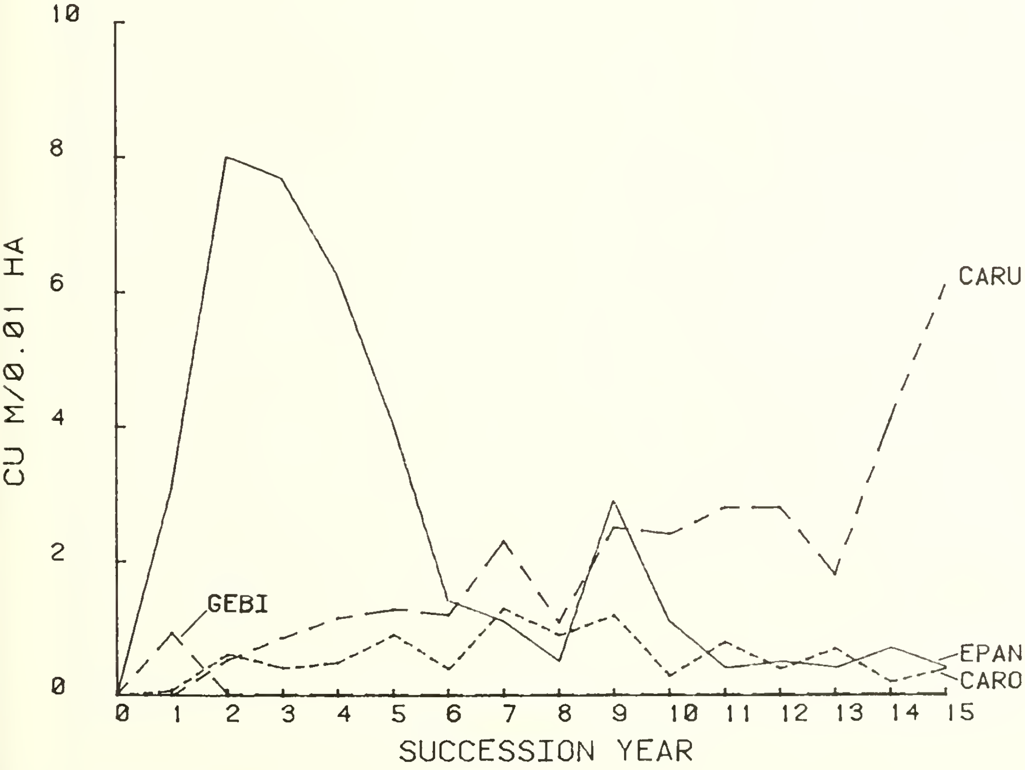


Figure 12-6.—Herb volume.

SUNDANCE BURN: 1802-16 Study Area SD-16

Site location and description: SW¼NE¼ sec. 9, T. 60 N., R. 2 W., BM; Elevation: 3,350 ft; Exposure: Southwest (Az. 240°); Slope: 30%

Forest cover type and tree size class: Douglas-fir immature poletimber, 70 through 100% crown coverage

Reconstructed prefire forest stand:
Tree component: Conifer density: 13.6/0.01 ha; Average d.b.h.: 15.0 cm; Basal area: 3,088 cm^2/0.01 ha
Shrub component: ACGL 11%, CESA 17%, ROGY 11%, SASC 56%, SYAL 5% (Shrub density: 7.2/0.01 ha);
Other species present: CEVE, PAMY, RUPA, SPBE

Disturbance treatment:
Wildfire: September 1, 1967 (1930 hrs); Succession year 1:1968;
Fire intensity: 3,400 to 22,500 Btu/sec/ft; Rate of spread: 1 to 6 mi/h;
Fire severity: R-N index: 5-M; Overstory crown foliage: Consumed; Litter-duff: Consumed

Table 13-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 13-1

Life form component	Succession year											
	1	2	3	4	5	6	7	8	9	10	11	12
Tree	--	--	--	--	--	--	--	--	1	2	1	4
Shrub	7	32	27	62	90	120	134	196	135	166	128	145
Herb	46	50	47	45	35	24	39	31	32	24	35	23
Total veg.	53	82	75	107	125	145	173	227	168	192	164	172

Table 13-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 13-2

Life form component	Succession year											
	1	2	3	4	5	6	7	8	9	10	11	12
Tree	--	--	--	--	--	--	--	--	1.0	4.8	3.3	11.9
Shrub	7.8	30.4	21.1	55.0	98.5	167.0	157.5	329.5	242.3	292.6	219.2	240.7
Herb	9.6	22.4	19.7	17.7	12.0	9.8	17.3	11.5	15.4	9.9	21.3	12.9
Total veg.	17.4	52.8	40.8	72.7	110.5	176.8	174.7	341.0	258.7	307.3	243.8	265.5

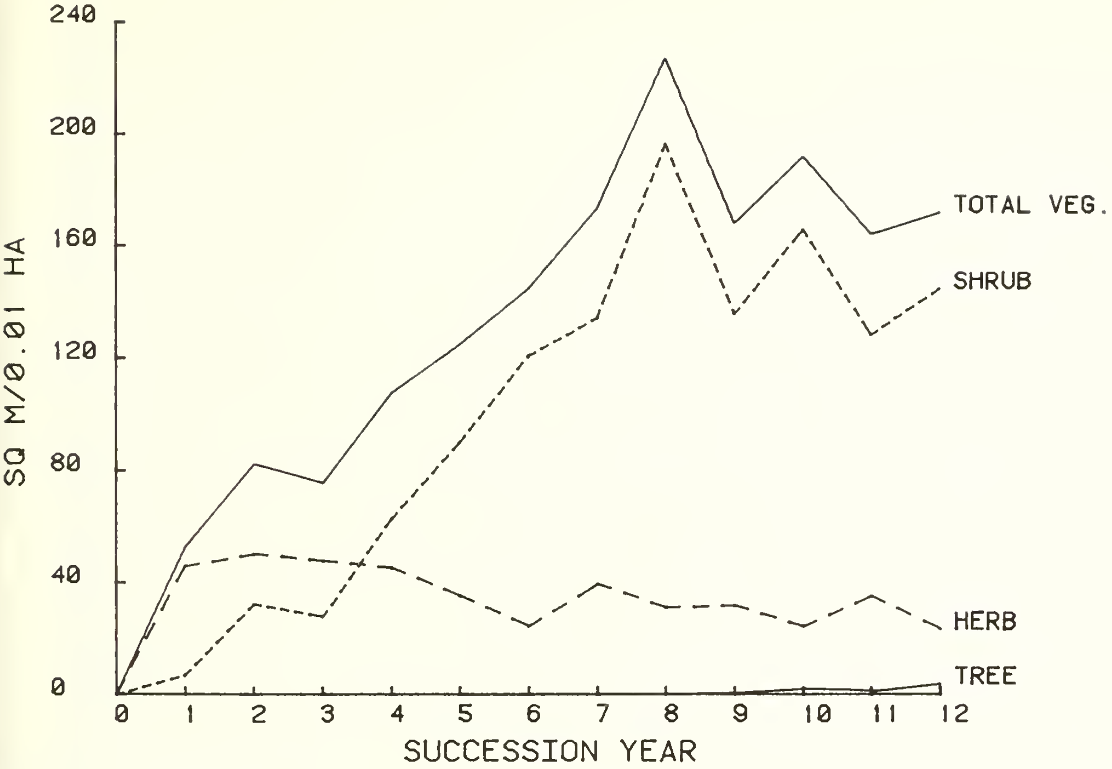


Figure 13-1.—Vegetative cover.

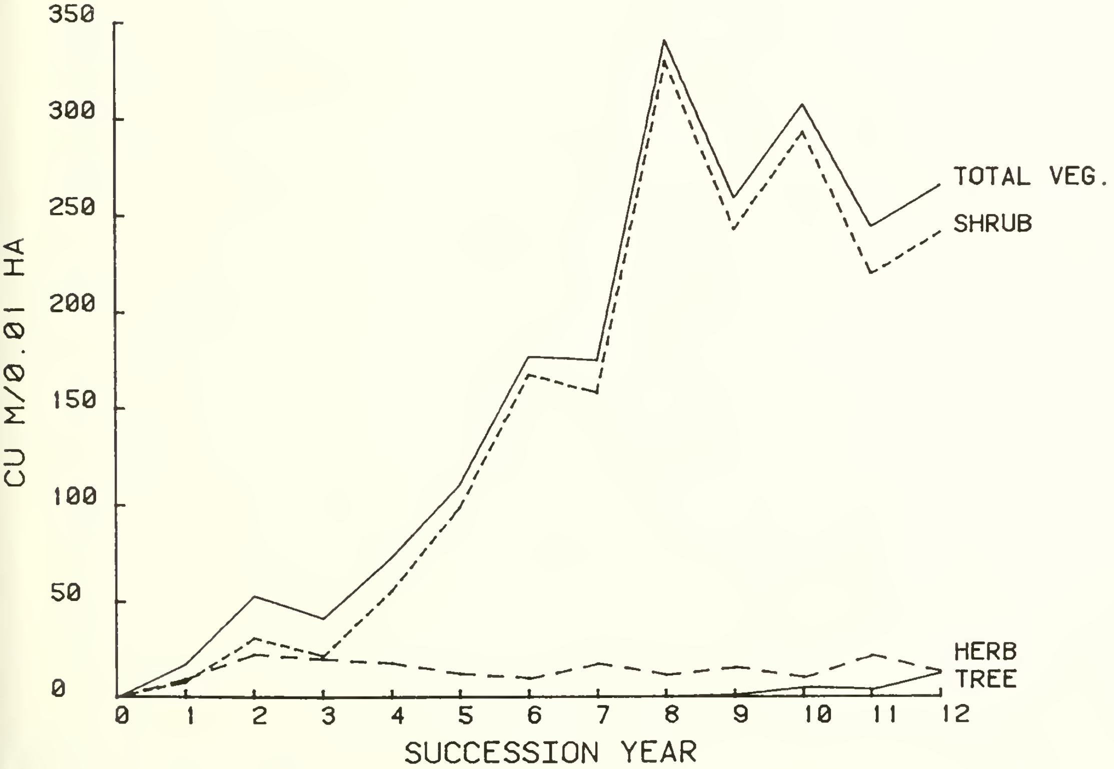


Figure 13-2.—Vegetative volume.

Table 13-3.--Cover development of tree and shrub components (m²/0.01 ha or %), fig. 13-3

Species	Succession year											
	1	2	3	4	5	6	7	8	9	10	11	12
Tree												
PICO	--	--	--	--	--	--	--	--	--	<1	<1	<1
PSME	--	--	--	--	--	--	--	--	1	2	1	4
Shrub												
ACGL	1	2	2	3	5	1	8	7	5	2	1	1
CESA	--	5	12	29	47	82	74	121	77	101	66	75
CEVE	--	--	--	--	--	--	<1	1	2	3	2	--
LOUT	--	--	--	<1	--	--	--	--	--	--	--	--
PAMY	--	--	--	1	1	1	2	4	6	6	6	9
ROGY	--	3	2	2	3	3	6	9	5	8	6	6
RUPA	--	3	--	2	6	5	3	5	5	7	7	3
SASC	6	14	11	21	23	22	31	39	28	27	30	34
SPBE	--	4	1	3	4	5	8	9	7	11	9	13
SYAL	--	<1	--	--	<1	1	1	<1	1	1	1	3

Table 13-4.--Cover development of herb component (m²/0.01 ha or %), fig. 13-4

Species	Succession year											
	1	2	3	4	5	6	7	8	9	10	11	12
AGAL	1	3	2	2	8	4	11	6	8	7	9	7
ANMA	--	--	--	--	1	1	2	1	1	1	1	1
APAN	--	--	--	--	--	--	--	1	--	1	--	--
CARO	3	5	6	3	3	2	6	6	7	6	8	6
DAGL	1	1	2	3	2	3	6	2	3	2	4	3
EPAN	27	34	29	26	15	6	2	4	2	2	3	2
GEBI	6	1	--	--	--	--	--	--	--	--	--	--
HIAL	--	--	--	--	--	--	--	--	--	--	1	--
ILRI	1	1	1	1	2	2	2	2	2	2	2	1
PHPR	--	--	--	--	--	--	1	--	--	--	--	--
PTAQ	2	1	2	5	1	2	7	6	7	2	6	3
Misc.	6	4	6	4	4	3	2	3	1	2	--	--

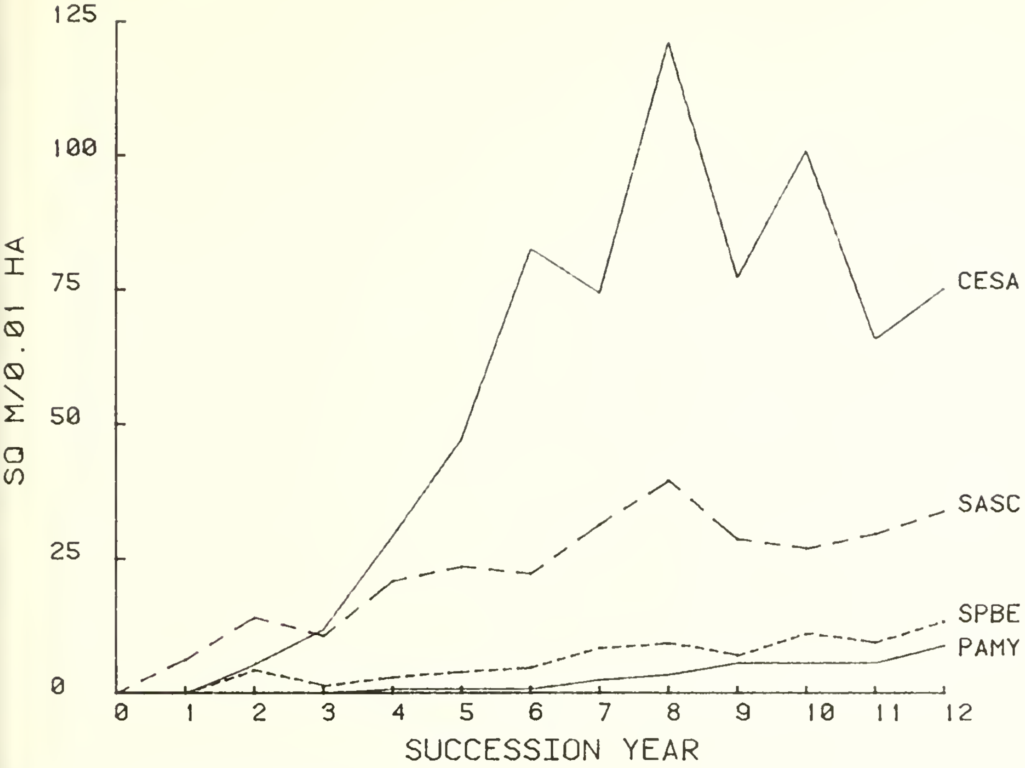


Figure 13-3.—Tree and shrub cover.

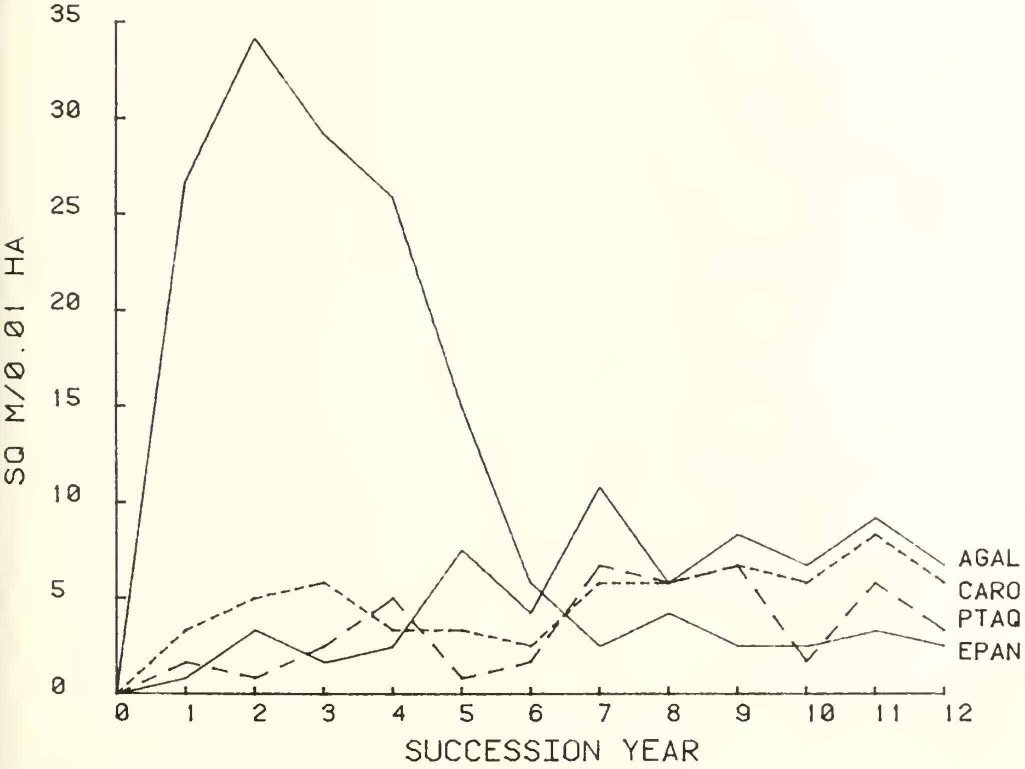


Figure 13-4.—Herb cover.

Table 13-5.--Volume development of tree and shrub components (m^3/0.01 ha), fig. 13-5

	Succession year											
Species	1	2	3	4	5	6	7	8	9	10	11	12
Tree												
PICO	--	--	--	--	--	--	--	--	--	0.4	0.3	0.4
PSME	--	--	--	--	--	--	--	--	1.0	4.4	3.0	11.5
Shrub												
ACCL	0.3	1.8	1.2	3.4	6.3	2.3	6.2	13.3	11.3	3.4	3.6	4.1
CESA	--	2.8	7.4	23.2	53.9	122.8	93.7	222.7	159.0	211.0	134.2	142.0
CEVE	--	--	--	--	--	--	.2	1.3	2.7	5.9	3.3	--
LOUT	--	--	--	.2	--	--	--	--	--	--	--	--
PAMY	--	--	--	.1	.2	.2	.7	1.4	2.1	2.3	2.3	4.2
ROGY	--	1.3	1.0	1.7	2.0	1.9	3.8	5.6	2.5	6.1	4.6	4.6
RUPA	--	1.2	--	.4	2.2	1.8	1.6	2.8	2.4	3.4	2.9	1.2
SASC	7.5	21.4	11.1	24.8	32.4	36.1	47.4	79.1	59.4	54.8	63.2	76.6
SPBE	--	1.9	.4	1.2	1.4	1.6	3.5	3.0	2.5	5.0	4.3	5.8
SYAL	--	<.1	--	--	.1	.3	.4	.3	.4	.7	.8	2.2

Table 13-6.--Volume development of herb component (m^3/0.01 ha), fig. 13-6

	Succession year											
Species	1	2	3	4	5	6	7	8	9	10	11	12
AGAL	0.1	2.6	0.5	0.9	2.9	2.3	7.0	2.0	4.9	2.9	6.9	5.0
ANMA	--	--	--	--	.2	.3	.7	.4	.7	.7	.6	.5
APAN	--	--	--	--	--	--	--	.3	--	.3	--	--
CARO	.3	.6	.7	.4	.3	.3	.9	.8	.9	.8	1.4	.6
DAGL	.1	.1	.4	.8	.4	.9	2.1	.9	2.0	1.3	2.8	1.5
EPAN	7.5	16.7	15.4	12.5	6.2	3.3	1.1	2.6	1.5	1.8	2.2	1.9
GEBI	.4	.2	--	--	--	--	--	--	--	--	--	--
HIAL	--	--	--	--	--	--	--	--	--	--	<.1	--
ILRI	.1	.3	.3	.3	.7	1.5	1.6	1.3	1.9	1.0	2.5	1.0
PHPR	--	--	--	--	--	--	.6	--	--	--	--	--
PTAQ	.3	.4	.9	2.0	.2	.5	2.5	2.7	3.4	.8	4.9	2.4
Misc.	.8	1.4	1.4	.8	1.1	.7	.8	.6	.2	.4	--	--

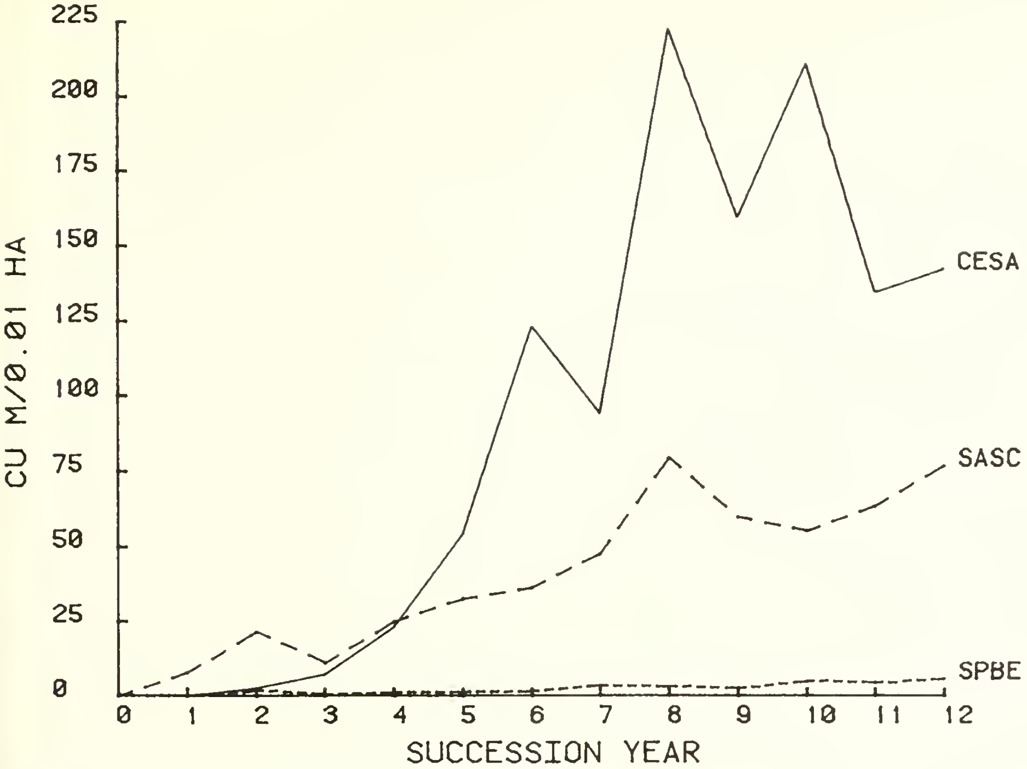


Figure 13-5.—Tree and shrub volume.

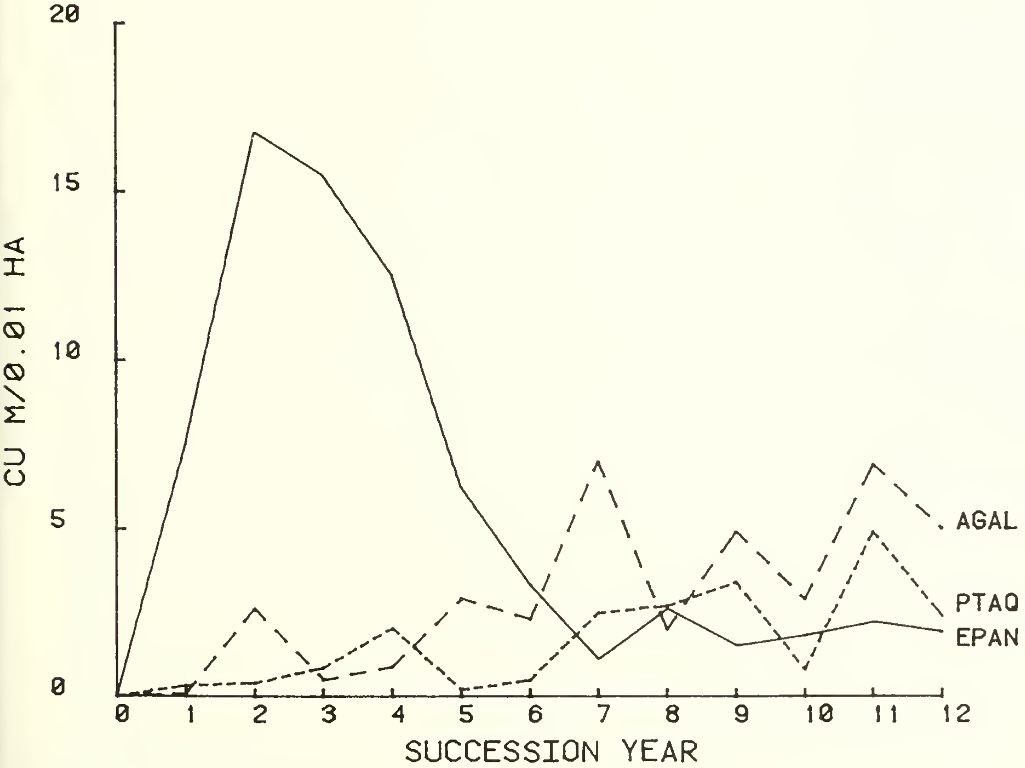


Figure 13-6.—Herb volume.

SUNDANCE BURN: 1802-16 Study Area SD-17

Site location and description: SE¼SE¼ sec. 9, T. 60 N., R. 2 W., BM; Elevation: 3,650 ft; Exposure: Southwest (Az. 240°); Slope: 30%

Forest cover type and tree size class: Western larch immature poletimber, 10 to 40% crown coverage

Reconstructed prefire forest stand:
Tree component: Conifer density: 1.6/0.01 ha; Average d.b.h.: 3.5 cm; Basal area: 18 cm^2/0.01 ha
Shrub component: ACGL 2%, AMAL 15%, CESA 21%, HODI 14%, PREM 3%, ROGY 1%, SASC 39%, SYAL 5% (Shrub density: 50.0/0.01 ha); Other species present: CEVE, LOUT, PAMY, SPBE, VAME

Disturbance treatment:
Wildfire: September 1, 1967 (1930-2000 hrs); Succession year 1:1968;
Fire intensity: 3,400 to 22,500 Btu/sec/ft; Rate of spread: 1 to 6 mi/h;
Fire severity: R-N index: 5-M to 5-D; Shrub overstory crown: Consumed, reduced to charred stubs at root crown; Litter-duff: Consumed

Table 14-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 14-1

Life form component	Succession year 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tree	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Shrub	50	60	115	104	140	144	138	170	131	143	157	139	155	193	183
Herb	41	62	52	49	47	32	48	48	50	46	51	53	49	47	44
Total veg.	91	122	168	153	187	177	186	219	181	189	208	192	204	240	227

Table 14-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 14-2

Life form component	Succession year 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tree	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Shrub	71.4	88.8	235.5	182.1	230.3	302.3	241.9	340.9	218.7	255.1	269.0	244.3	268.5	334.3	351.2
Herb	6.5	18.0	12.4	14.7	10.5	8.6	15.6	14.9	14.4	13.4	15.9	17.4	17.9	15.9	17.2
Total veg.	77.9	106.8	247.9	196.7	240.8	310.9	257.5	355.8	233.1	268.5	284.9	261.7	286.4	350.2	368.4

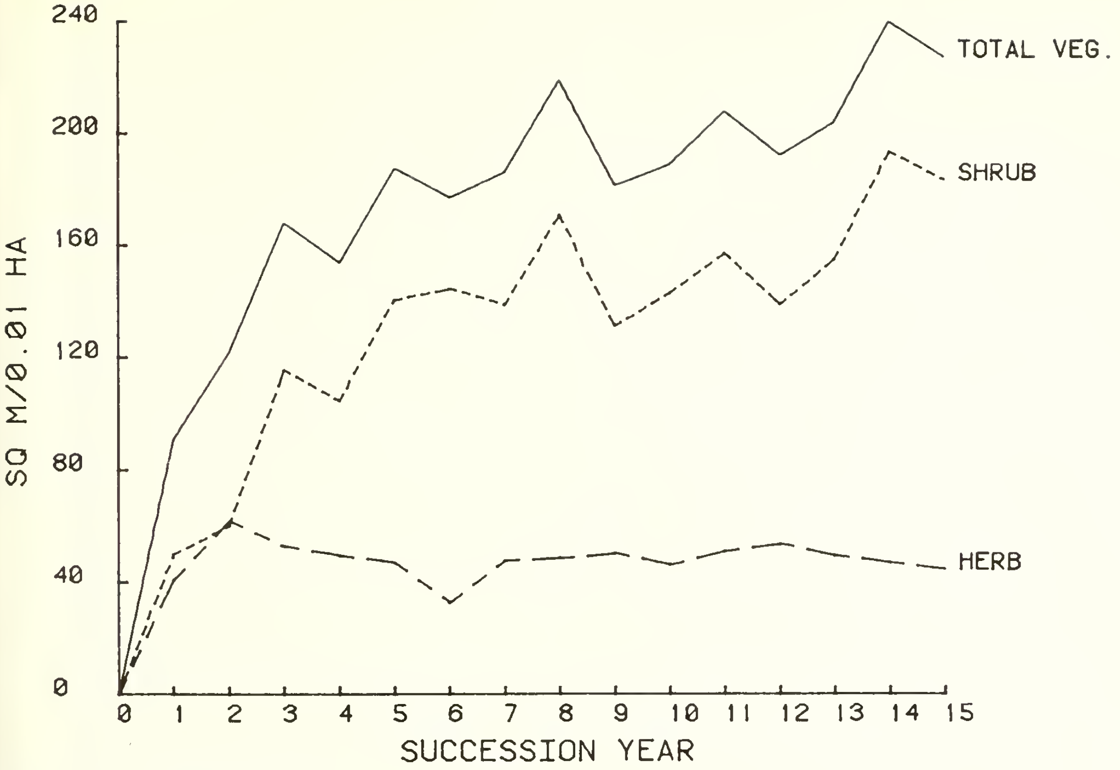


Figure 14-1.—Vegetative cover.

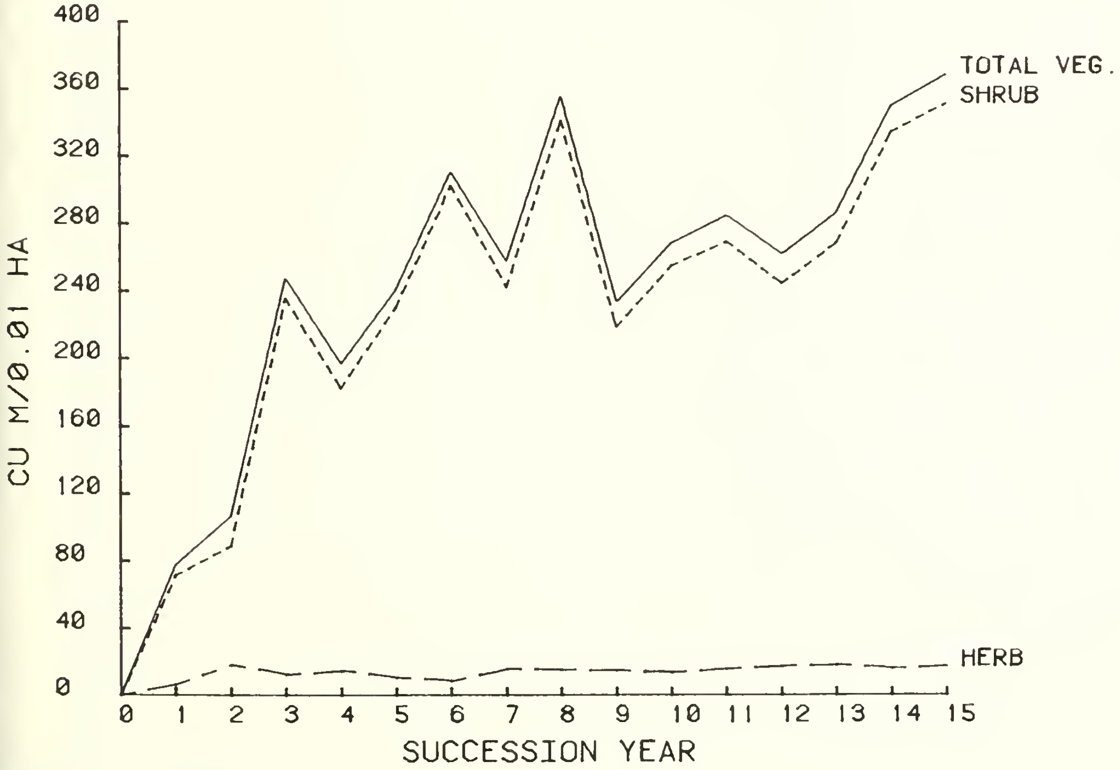


Figure 14-2.—Vegetative volume.

Table 14-3.--Cover development of shrub component ($m^2/0.01$ ha or %), fig. 14-3

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
ACGL	1	1	2	2	3	3	1	2	3	3	4	4	3	4	3
AMAL	1	2	4	8	9	11	13	16	9	6	6	12	9	11	10
CESA	9	16	13	20	50	22	20	26	28	48	47	30	46	85	67
CEVE	--	--	--	--	--	--	--	1	1	--	--	--	--	--	--
HODI	2	1	2	6	4	8	10	11	7	9	13	3	9	6	7
PAMY	--	5	4	8	9	11	20	16	18	15	24	27	28	25	26
PREM	--	--	<1	--	1	1	2	1	1	<1	<1	1	--	1	<1
ROGY	1	2	6	7	9	9	7	8	9	8	11	8	8	9	7
SASC	34	30	75	47	46	72	60	75	46	48	46	50	49	49	54
SPBE	1	2	3	3	3	3	2	2	4	3	2	1	2	2	2
SYAL	1	1	6	4	6	5	4	11	5	3	4	3	<1	3	5
VAME	--	--	--	1	--	--	--	--	--	--	--	--	1	--	--

Table 14-4.--Cover development of herb component ($m^2/0.01$ ha or %), fig. 14-4

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
ACMI	--	--	--	--	--	--	--	--	--	1	1	1	--	--	--
CARU	8	22	21	17	22	18	33	25	25	23	26	26	29	30	28
CAGE	--	--	--	--	--	--	--	--	--	--	1	1	1	1	--
CARO	2	6	2	5	7	4	1	--	4	1	2	2	1	1	2
CRAF	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--
EPAN	1	1	2	2	2	1	2	3	2	2	1	1	1	--	1
FRVE	--	--	--	--	--	--	--	--	1	--	--	1	2	2	2
LICO	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--
LUAR	18	25	19	19	8	4	10	9	13	12	13	19	13	11	8
THOC	--	1	2	2	2	1	1	5	3	5	7	3	2	2	5
Misc.	9	8	7	4	6	4	1	6	1	2	--	--	--	--	--

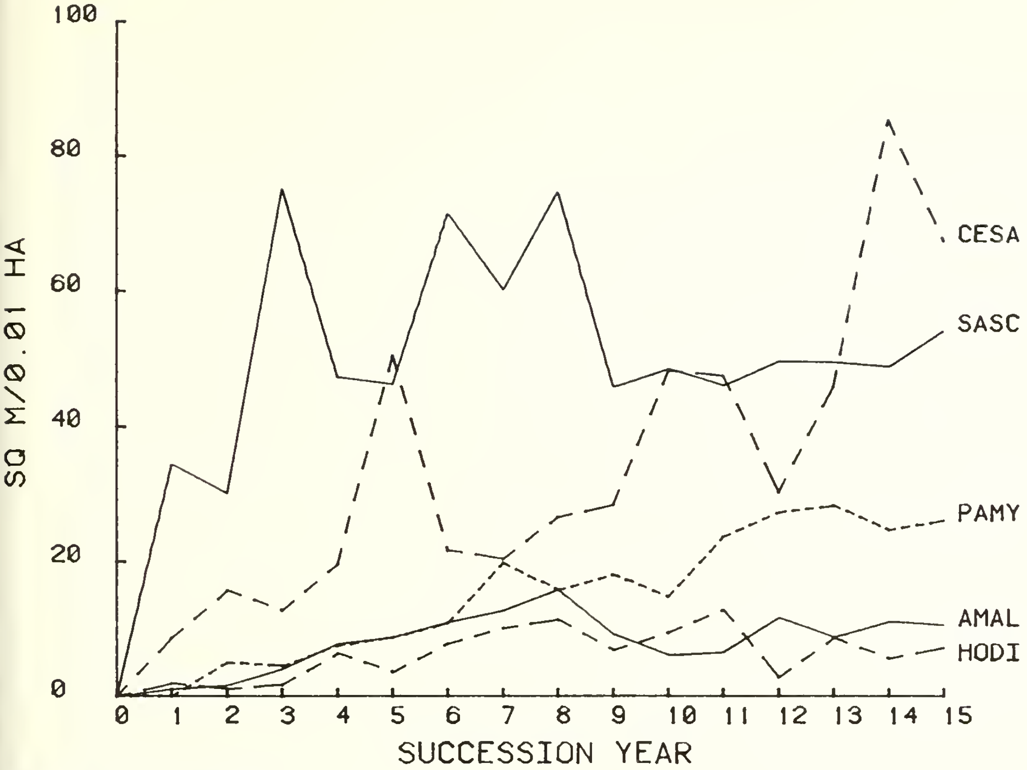


Figure 14-3.—Shrub cover.

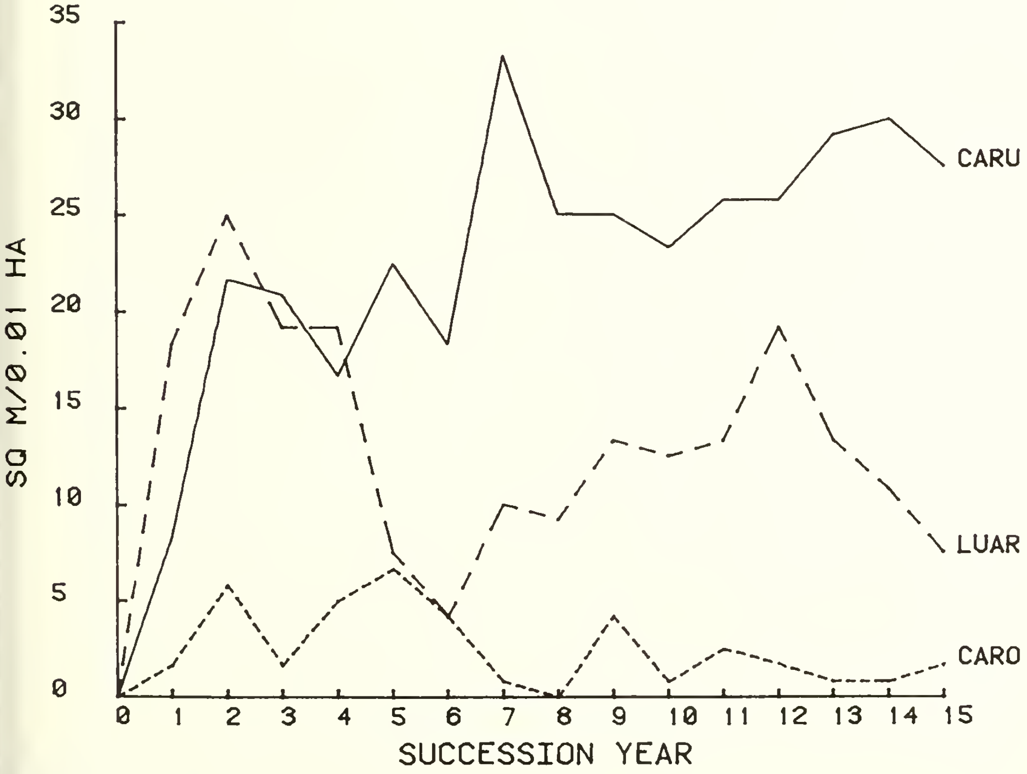


Figure 14-4.—Herb cover.

Table 14-5.--Volume development of shrub component (m^3/0.01 ha), fig. 14-5

Species	Succession year 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
ACGL	0.8	1.9	2.9	2.9	4.7	5.8	1.0	3.4	4.5	4.1	5.5	6.4	4.6	5.5	5.5
AMAL	.5	1.2	3.0	8.1	9.2	11.5	14.2	19.2	9.3	6.8	8.4	16.8	12.1	15.5	16.8
CESA	3.6	12.1	8.3	15.0	49.0	25.1	13.7	18.8	23.0	59.0	60.8	26.3	44.7	108.8	94.5
CEVE	--	--	--	--	--	--	--	.6	.5	--	--	--	--	--	--
HODI	1.5	1.5	2.8	9.8	6.0	13.3	11.0	19.3	11.3	14.5	19.2	4.8	11.7	10.1	14.1
PAMY	--	.8	.9	1.7	2.4	3.6	7.8	6.5	7.6	6.4	10.0	12.3	14.4	12.3	13.2
PREM	--	--	<.1	--	.7	1.2	3.1	1.5	1.1	.4	.6	2.0	--	1.0	.1
ROGY	.1	.5	2.1	2.8	3.8	3.7	3.5	4.6	4.0	4.3	6.3	4.8	4.8	5.3	4.1
SASC	64.1	69.1	211.7	139.1	150.7	234.4	184.3	260.2	154.7	157.8	156.4	169.4	175.3	174.2	200.6
SPBE	.2	.8	.6	.8	.8	1.2	.5	.7	1.0	.7	.5	.3	.7	.5	.6
SYAL	.6	.8	3.2	1.4	3.0	2.6	2.7	6.1	1.8	1.3	1.3	1.3	.2	1.2	1.8
VAME	--	--	--	.4	--	--	--	--	--	--	--	--	<.1	--	--

Table 14-6.--Volume development of herb component (m^3/0.01 ha), fig. 14-6

Species	Succession year 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
ACMI	--	--	--	--	--	--	--	--	--	0.2	0.1	0.1	--	--	--
CARU	2.0	7.0	5.2	5.0	5.9	5.3	10.5	7.3	7.1	7.0	9.1	8.9	10.7	11.0	11.8
CAGE	--	--	--	--	--	--	--	--	--	--	.3	.2	.2	.2	--
CARO	.1	.5	.2	.6	.6	.4	.1	--	.5	<.1	.3	.2	.1	.1	.3
CRAF	.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--
EPAN	.3	.2	2.1	2.2	.8	.7	1.2	1.8	1.0	.8	.6	.8	.9	--	.7
FRVE	--	--	--	--	--	--	--	--	<.1	--	--	.1	.1	.2	.3
LICO	--	--	--	--	--	--	--	--	.4	--	--	--	--	--	--
LUAR	2.5	8.7	3.2	5.5	1.2	.8	3.3	2.5	3.8	3.2	3.2	5.8	4.3	3.6	1.7
THOC	--	.2	.4	.7	1.0	.4	.4	2.1	1.3	1.9	2.3	1.3	1.6	.8	2.5
Misc.	1.2	1.4	1.3	.6	1.0	.9	.1	1.3	.2	.3	--	--	--	--	--

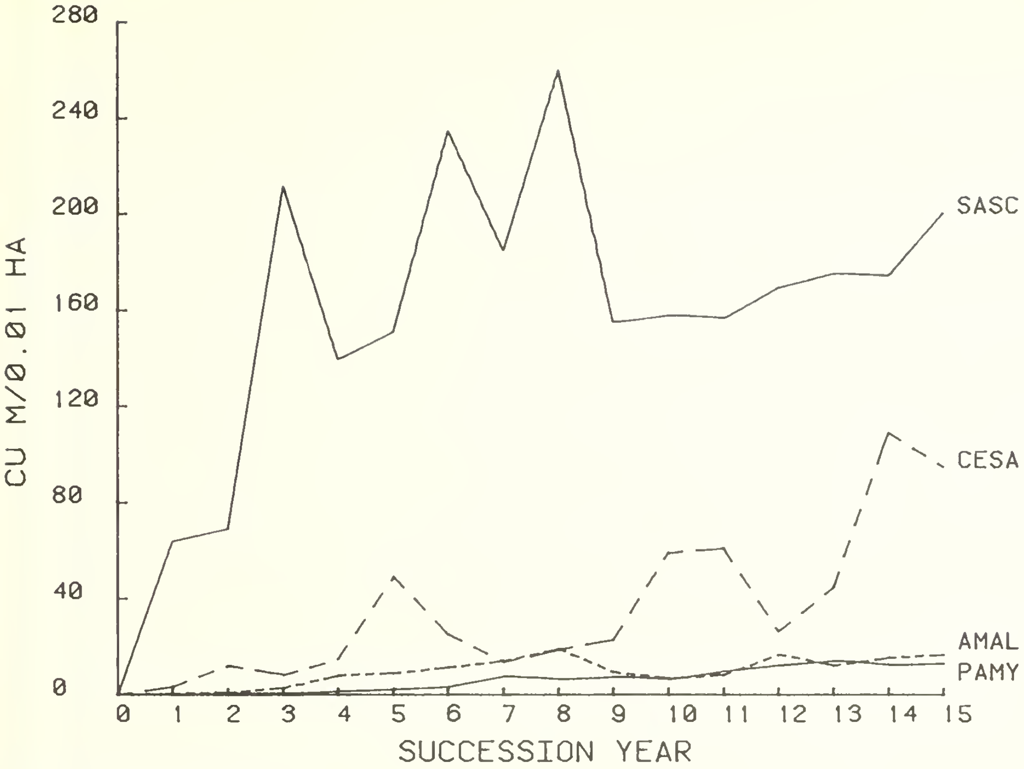


Figure 14-5.—Shrub volume.

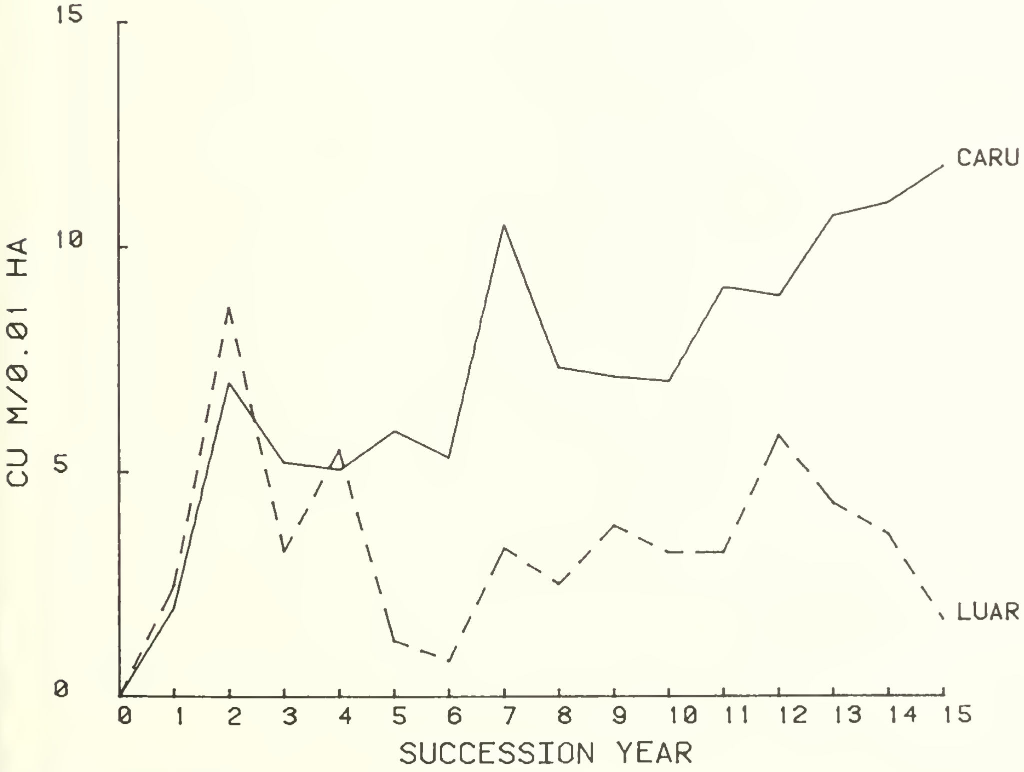


Figure 14-6.—Herb volume.

SUNDANCE BURN: 1802-16 Study Area SD-18

Site location and description: SE¼SE¼ sec. 9, T. 60 N., R. 2 W., BM; Elevation: 3,550 ft; Exposure: Southwest (Az. 245°); Slope: 35%

Forest cover type and tree size class: Western larch immature poletimber, 10 to 40% crown cover

Reconstructed prefire forest stand:

Tree component: Conifer density 10.8/0.01 ha, paper birch density 4.4/0.01 ha; Average diameter: Conifer 10.9 cm, paper birch 11.8 cm; Basal area: Conifer 1,391 cm^2/0.01 ha, Paper birch 901 cm^2/0.01 ha

Shrub component: AMAL 20%, CESA 8%, HODI 6%, PREM 1%, ROGY 11%, SASC 52%, SYAL 2% (Shrub density: 40.0/0.01 ha); Other species present: ACGL, CEVE, LOUT, PAMY, RUPA, SPBE, VAME

Disturbance treatment:

Wildfire: September 1, 1967 (1930-2000 hrs); Succession year 1:1968;

Fire intensity: 3,400 to 22,500 Btu/sec/ft; Rate of spread: 1 to 6 mi/h;

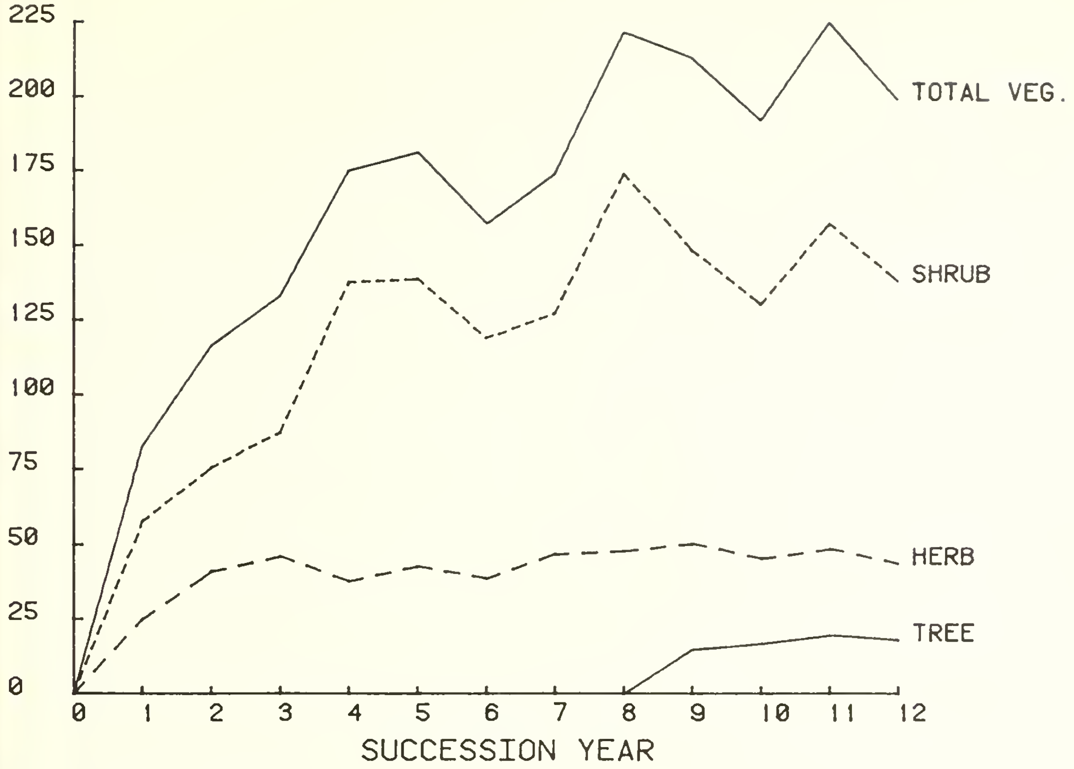
Fire severity: R-N index: 5-M; Overstory crown foliage: Consumed; Litter-duff: Consumed

Table 15-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 15-1

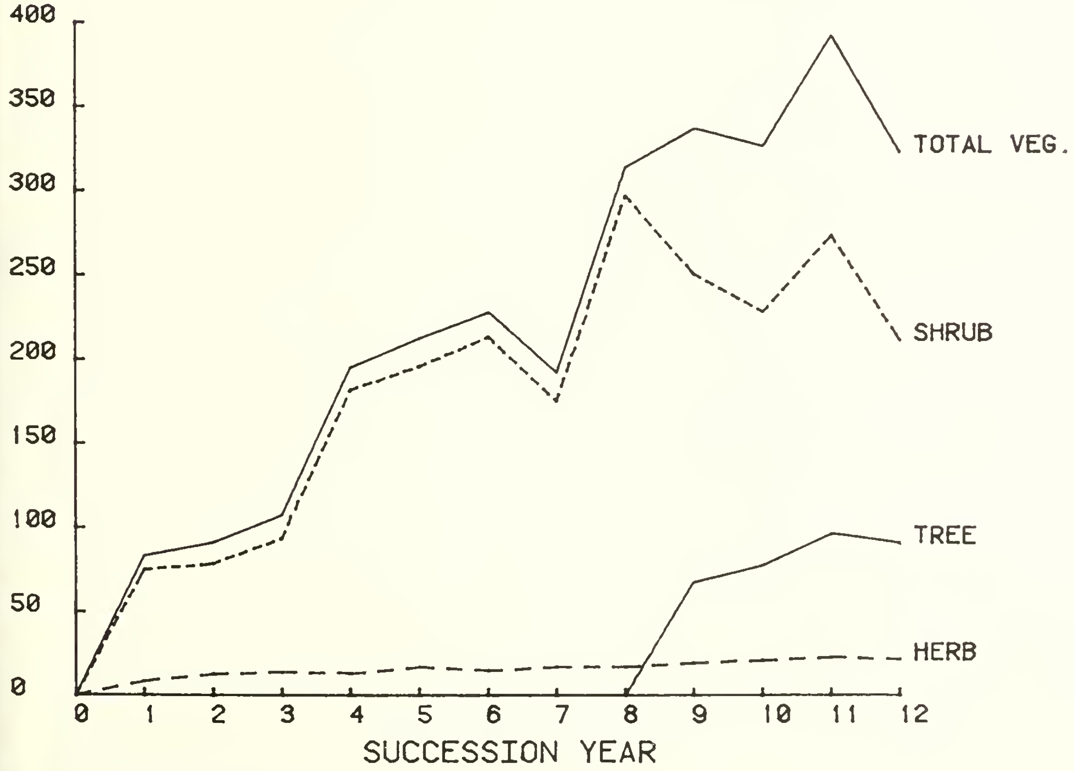
Life form component	Succession year											
	1	2	3	4	5	6	7	8	9	10	11	12
Tree	--	--	--	--	--	--	--	<1	15	17	19	18
Shrub	58	75	87	137	138	119	127	174	148	130	157	138
Herb	25	41	46	37	42	38	47	48	50	45	48	43
Total veg.	83	116	133	175	181	157	174	221	212	191	225	199

Table 15-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 15-2

Life form component	Succession year											
	1	2	3	4	5	6	7	8	9	10	11	12
Tree	--	--	--	--	--	--	--	0.1	67.2	77.4	96.2	90.4
Shrub	75.0	78.4	93.3	181.6	195.4	212.9	174.6	296.7	250.0	227.7	273.1	210.7
Herb	8.6	12.8	13.9	13.3	16.8	14.7	16.8	17.0	19.4	20.8	22.5	21.2
Total veg.	83.6	91.2	107.2	194.9	212.2	227.6	191.4	313.7	336.6	325.8	391.8	322.3



gure 15-1.—Vegetative cover.



gure 15-2.—Vegetative volume.

Table 15-3.--Cover development of tree and shrub components (m^2/0.01 ha or %), fig. 15-3

	Succession year											
Species	1	2	3	4	5	6	7	8	9	10	11	12
Tree												
BEPA	--	--	--	--	--	--	--	--	14	16	18	16
PSME	--	--	--	--	--	--	--	<1	<1	1	2	1
Shrub												
AMAL	3	6	5	14	9	12	5	15	10	7	8	12
CESA	13	25	37	76	80	43	53	74	72	67	78	54
CEVE	--	--	--	--	--	--	--	--	--	--	<1	--
HODI	--	1	--	5	3	5	3	5	4	4	3	3
PAMY	--	2	1	2	2	3	3	8	8	7	12	16
ROGY	---	<1	1	--	2	2	2	3	2	1	4	5
RUPA	5	10	16	8	15	8	13	12	9	10	12	8
SASC	35	26	24	25	22	37	40	49	31	24	30	30
SPBE	2	6	4	8	6	8	7	8	10	6	8	6
SYAL	--	--	--	--	--	1	1	--	<1	2	<1	1
VAME	--	--	--	--	--	1	1	--	2	2	2	2

Table 15-4.--Cover development of herb component (m^2/0.01 ha or %), fig. 15-4

	Succession year											
Species	1	2	3	4	5	6	7	8	9	10	11	12
AGAL	--	2	1	2	2	2	2	2	1	--	1	1
APAN	--	1	1	--	--	--	--	--	1	1	--	1
BERE	--	--	--	--	--	--	--	--	1	--	--	--
CARU	12	15	19	14	17	16	23	22	24	18	25	23
CARO	--	1	--	1	1	3	5	2	4	--	2	2
DAGL	--	--	--	--	--	1	1	1	--	1	1	2
EPAN	5	9	8	6	9	7	9	8	7	8	8	4
ILRI	1	--	1	--	--	--	--	1	--	--	--	--
LUAR	--	--	--	1	1	--	--	--	1	1	--	--
PTAQ	2	3	5	6	6	6	4	5	8	8	8	8
THOC	--	--	--	--	--	--	--	1	2	1	1	1
XETE	--	--	--	1	1	1	2	2	2	2	2	2
Misc.	5	10	11	8	7	3	1	4	1	4	1	--

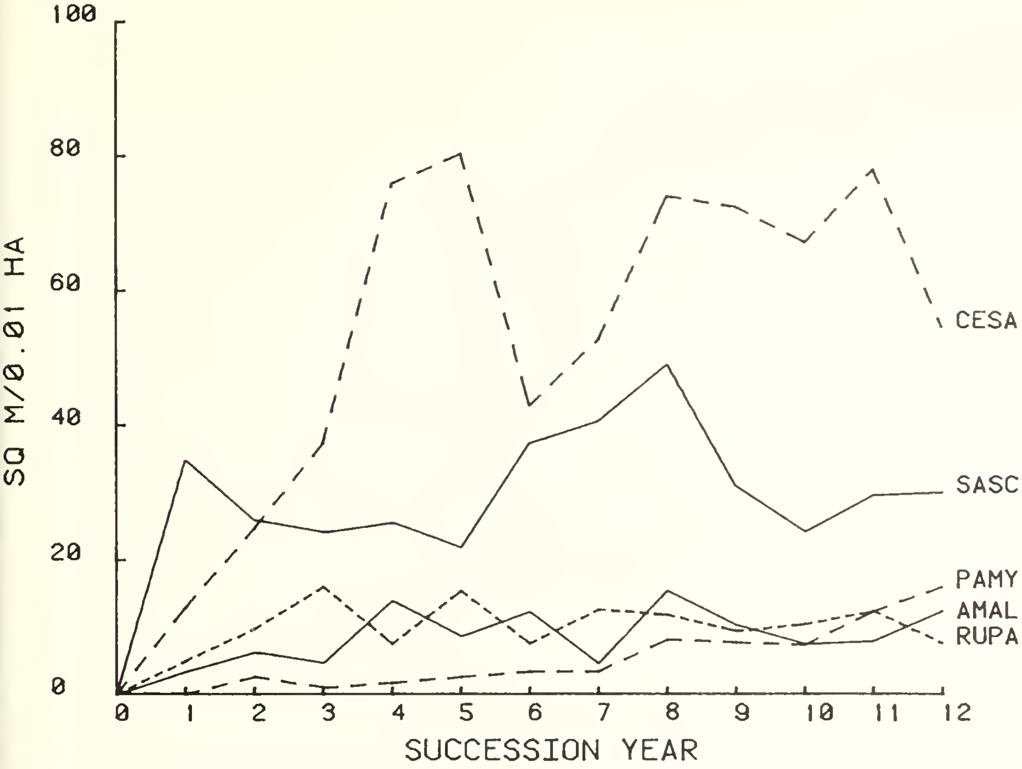


Figure 15-3.—Tree and shrub cover.

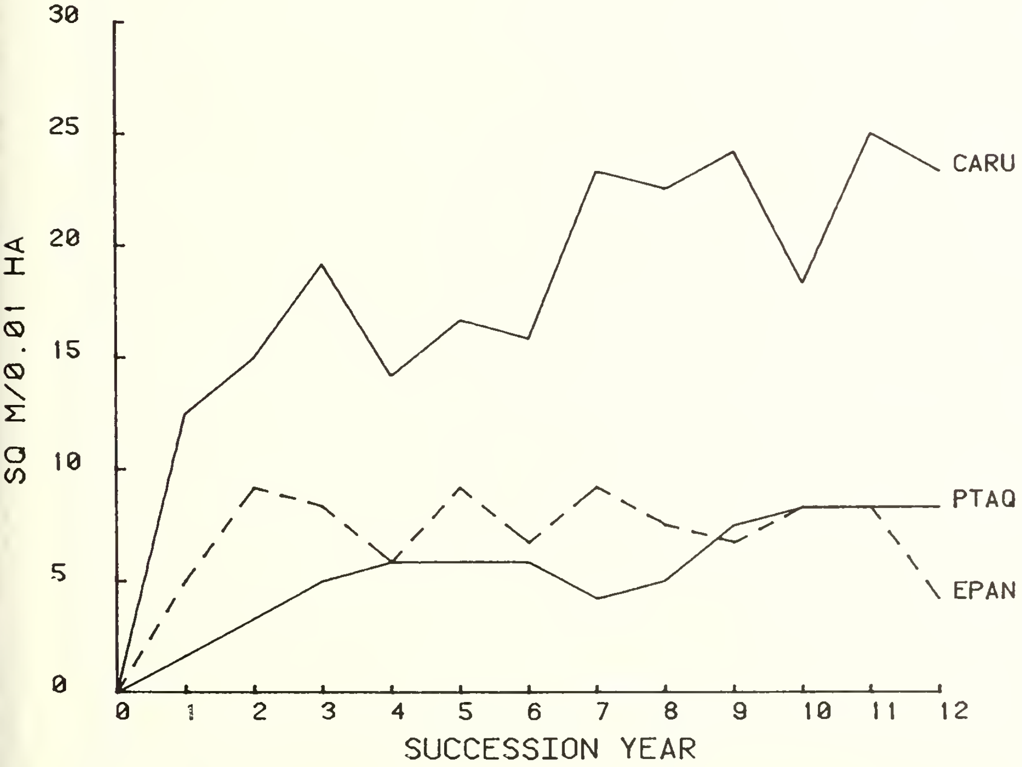


Figure 15-4.—Herb cover.

Table 15-5.--Volume development of tree and shrub components (m^3/0.01 ha), fig. 15-5

	Succession year											
Species	1	2	3	4	5	6	7	8	9	10	11	12
Tree												
BEPA	--	--	--	--	--	--	--	--	67.0	76.4	94.2	88.3
PSME	--	--	--	--	--	--	--	0.1	.2	.9	2.0	2.1
Shrub												
AMAL	2.2	6.2	4.5	14.6	7.7	14.4	4.4	16.6	11.3	7.6	11.3	20.4
CESA	14.4	12.8	24.3	84.0	113.0	68.5	56.5	113.6	120.3	123.6	138.3	59.5
CEVE	--	--	--	--	--	--	--	--	--	--	.7	--
HODI	--	.9	--	9.0	5.5	10.7	6.0	9.7	8.4	7.7	6.4	6.6
PAMY	--	.2	.2	.3	.4	.8	.9	2.9	2.9	2.6	4.6	6.5
ROGY	--	.1	.3	--	.9	.9	.8	2.0	.4	.4	2.4	3.0
RUPA	.6	3.7	5.5	2.4	6.0	2.4	4.5	3.9	3.4	3.6	4.1	2.6
SASC	57.4	52.0	57.1	69.0	60.5	112.5	98.7	145.9	98.4	78.9	102.2	108.7
SPBE	.4	2.5	1.4	2.3	1.4	2.3	2.4	2.0	3.8	1.9	2.5	2.1
SYAL	--	--	--	--	--	.3	.3	--	.2	.9	.2	.8
VAME	--	--	--	--	--	.1	.2	--	.6	.4	.4	.6

Table 15-6.--Volume development of herb component (m^3/0.01 ha), fig. 15-6

	Succession year											
Species	1	2	3	4	5	6	7	8	9	10	11	12
AGAL	--	1.2	0.2	1.0	1.2	0.8	1.2	0.8	0.5	--	0.9	0.8
APAN	--	.1	.1	--	--	--	--	--	.2	0.2	--	.2
BERE	--	--	--	--	--	--	--	--	.1	--	--	--
CARU	6.0	4.6	5.2	4.3	4.3	4.7	7.3	6.9	7.7	5.6	9.4	8.3
CARO	--	.1	--	<.1	.1	.4	.5	.3	.7	--	.2	.2
DAGL	--	--	--	--	--	.3	.5	.3	--	.3	.7	.8
EPAN	1.5	3.7	3.4	2.8	6.0	4.4	4.2	3.9	3.9	5.8	4.7	3.8
ILRI	<.1	--	.1	--	--	--	--	.5	--	--	--	--
LUAR	--	--	--	.2	.1	--	--	--	.2	.2	--	--
PTAQ	.3	1.3	2.7	3.2	3.5	3.3	2.6	2.6	5.1	6.7	5.6	6.3
THOC	--	--	--	--	--	--	--	.3	.5	.2	.3	.3
XETE	--	--	--	.2	.2	.2	.4	.5	.5	.9	.6	.5
Misc.	.8	1.8	2.1	1.5	1.4	.7	.2	.8	.1	1.1	.2	--

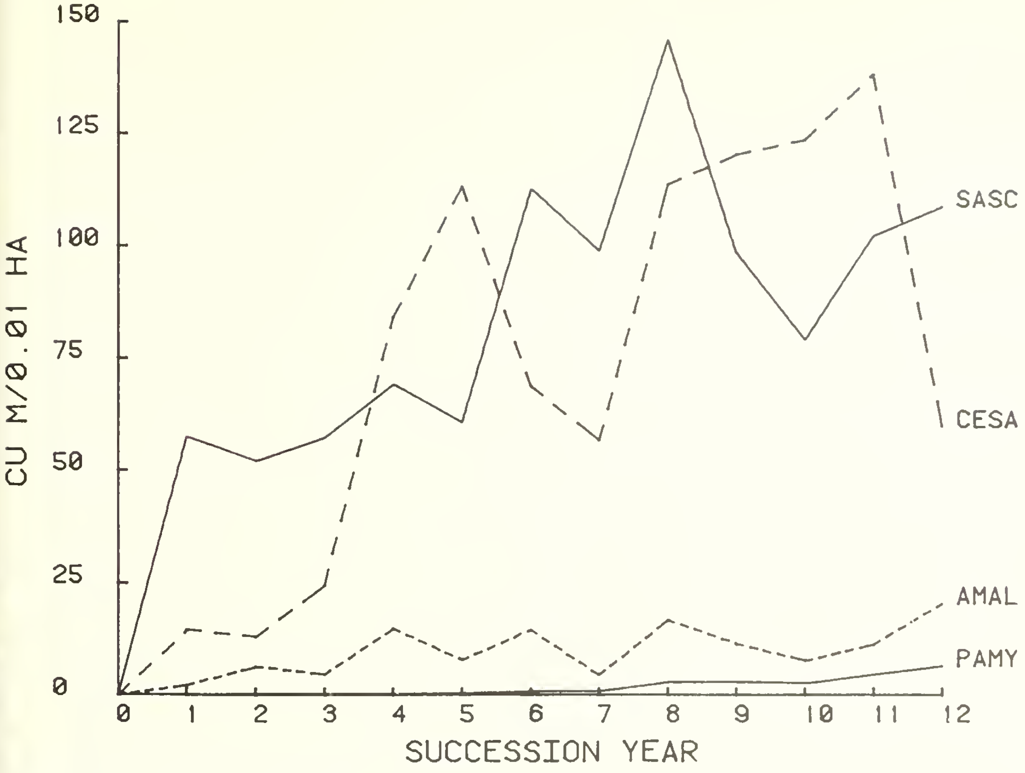


Figure 15-5.—Tree and shrub volume.

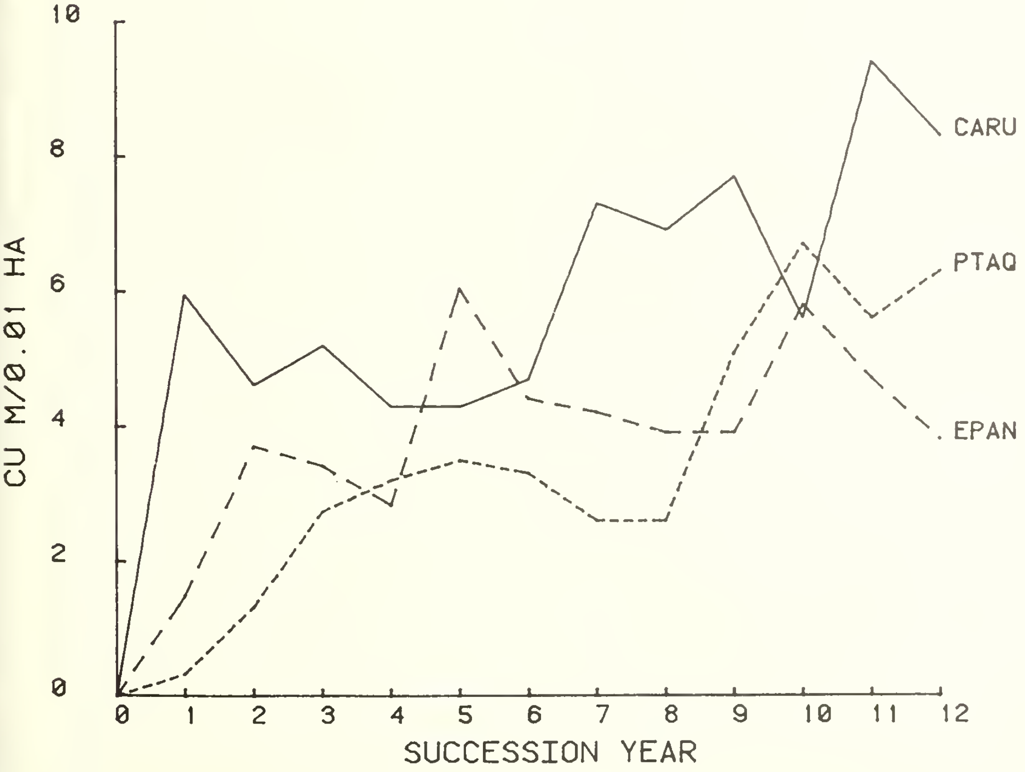


Figure 15-6.—Herb volume.

SUNDANCE BURN: 1802-16 Study Area SD-19

Site location and description: SW¼NE¼ sec. 30, T. 60 N., R. 2 W., BM; Elevation: 4,250 ft; Exposure: Southeast (Az. 115°); Slope: 25%

Forest cover type and tree size class: Western white pine immature poletimber, 70 through 100% crown cover

Reconstructed prefire forest stand:
Tree component: Conifer density: 29.2/0.01 ha; Average d.b.h.: 13.7 cm; Basal area: 5,477 cm^2/0.01 ha
Shrub component: ALSI 71%, SASC 29% (Shrub density: 2.8/0.01 ha);
Other species present: AMAL, LOUT, PAMY, RUPA

Disturbance treatment:
Wildfire: September 1, 1967 (1930-2200 hrs); Succession year 1:1968;
Fire intensity: 3,400 to 22,500 Btu/sec/ft; Rate of spread: -- mi/h;
Fire severity: R-N index: 5-M; Overstory crown foliage: Consumed; Litter-duff: Consumed

Table 16-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 16-1

Life form component	Succession year														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tree	--	--	--	--	--	7	--	25	37	49	64	73	96	87	105
Shrub	1	7	12	16	36	21	--	40	28	32	26	43	69	61	103
Herb	17	27	41	33	36	26	--	39	52	51	48	62	58	73	62
Total veg.	17	35	53	49	72	54	--	104	118	131	138	177	224	221	270

Table 16-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 16-2

Life form component	Succession year														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tree	--	--	--	--	--	3.0	--	22.7	46.3	77.6	125.6	170.6	276.2	285.4	383.6
Shrub	0.1	2.6	5.2	8.1	31.8	25.6	--	56.2	42.2	37.6	30.1	62.1	120.0	116.0	235.1
Herb	3.0	10.0	15.2	13.8	16.1	10.4	--	14.0	23.1	25.6	26.4	36.2	32.6	60.8	50.2
Total veg.	3.1	12.6	20.4	21.9	47.9	39.0	--	92.9	111.7	140.8	182.1	268.8	428.8	462.1	669.0

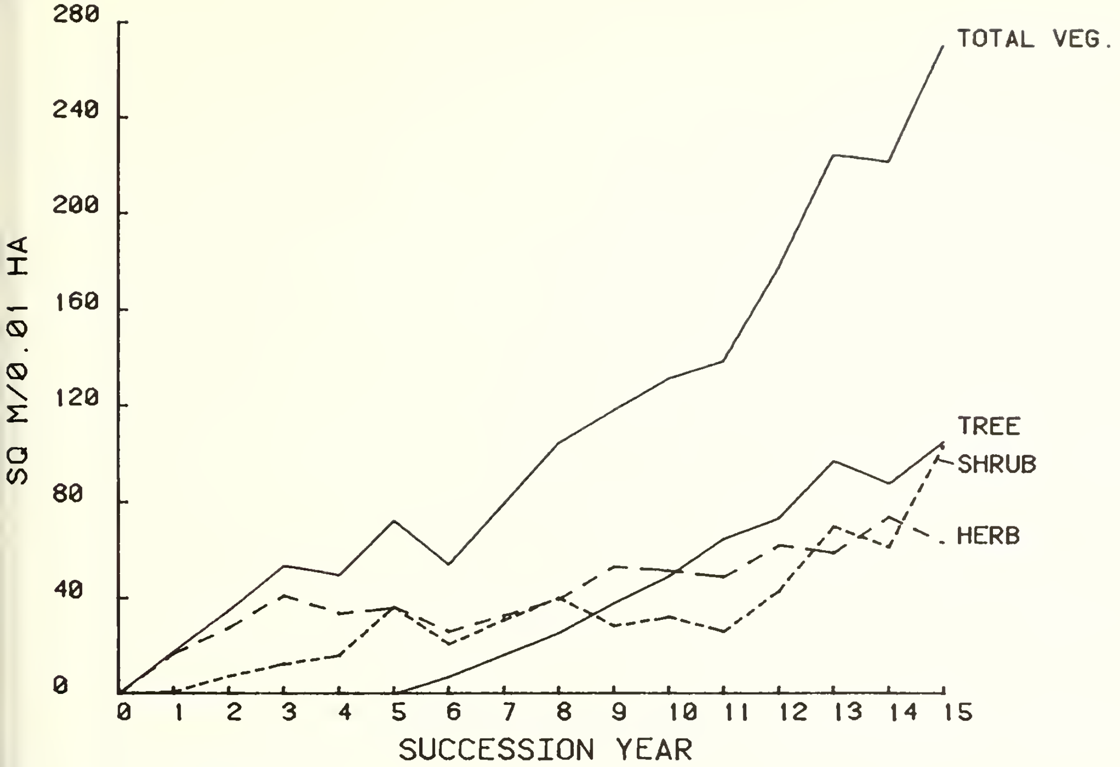


Figure 16-1.—Vegetative cover.

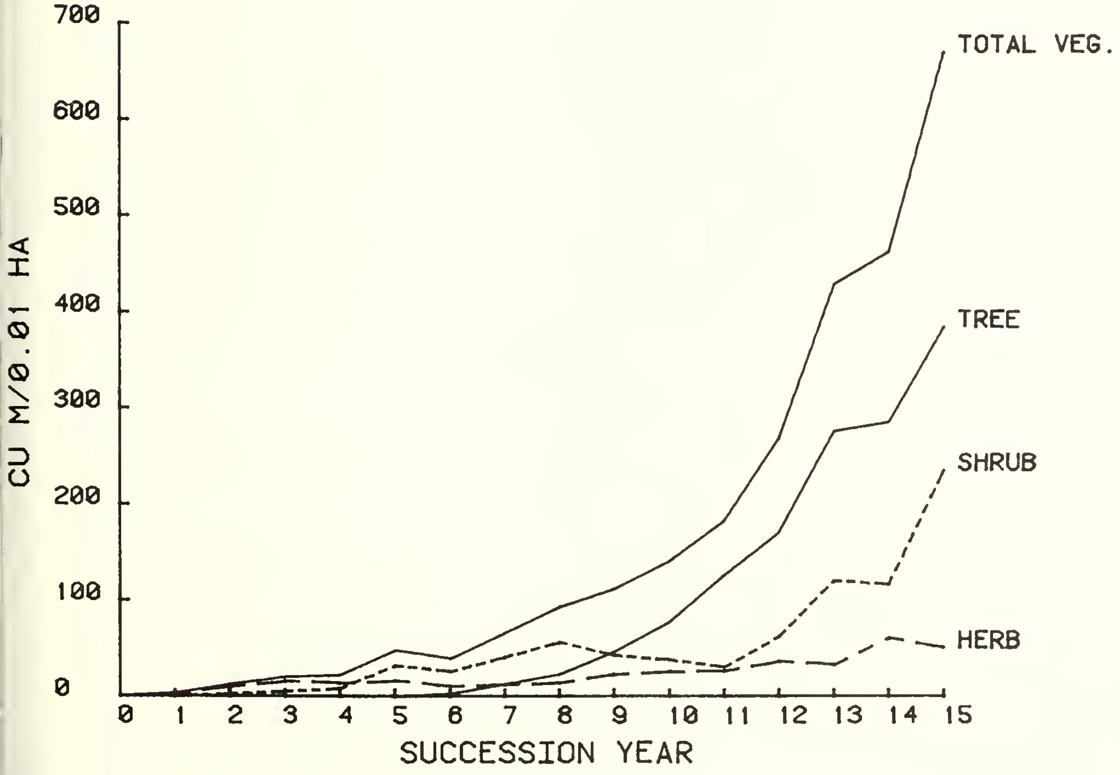


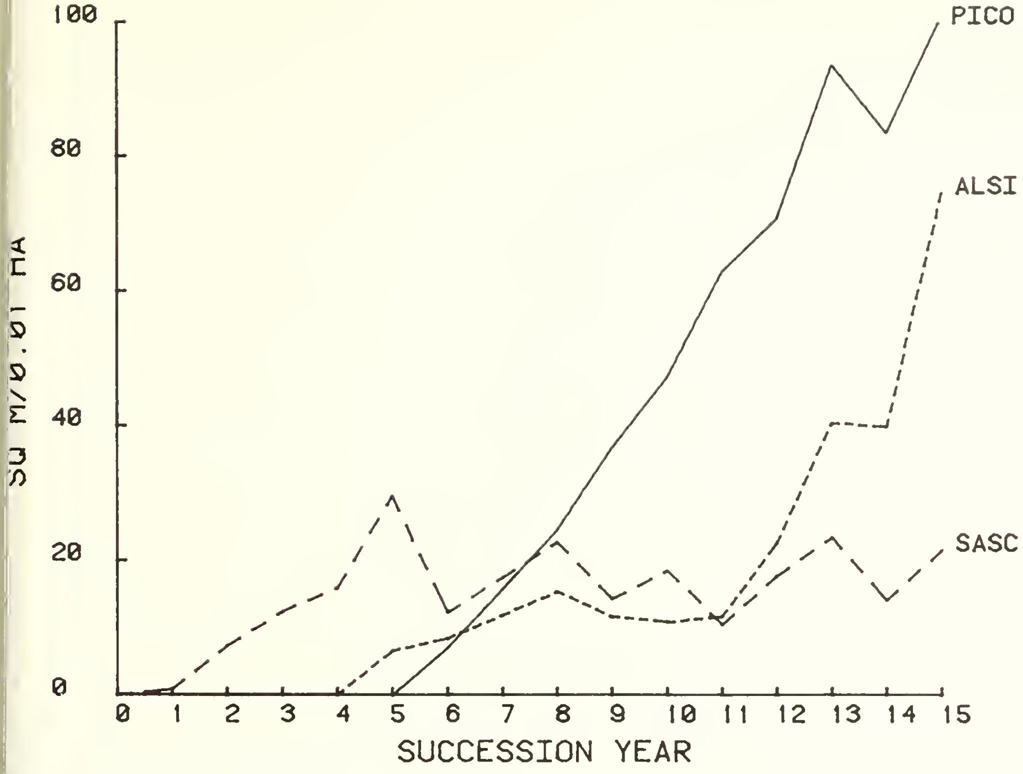
Figure 16-2.—Vegetative volume.

Table 16-3.--Cover development of tree and shrub components ($m^2/0.01$ ha or %), fig. 16-3

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tree															
PIEN	--	--	--	--	--	--	--	1	1	1	1	2	3	3	3
PICO	--	--	--	--	--	7	--	24	37	47	63	71	94	84	101
PIMO	--	--	--	--	--	--	--	--	--	--	--	--	--	<1	<1
Shrub															
ALSI	--	--	--	--	7	8	--	15	12	11	12	22	40	40	75
PAMY	--	--	--	--	--	--	--	--	--	--	1	1	1	2	1
RIVI	--	--	--	--	--	--	--	1	1	1	1	1	1	1	2
RUPA	--	--	--	--	--	--	--	1	2	2	2	1	3	4	4
SASC	1	7	12	16	29	12	--	23	14	18	10	18	23	14	21

Table 16-4.--Cover development of herb component ($m^2/0.01$ ha or %), fig. 16-4

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
ANMA	--	--	--	--	--	1	--	7	9	4	2	1	2	1	--
APAN	--	--	--	--	--	--	--	--	--	--	--	3	--	2	--
EPAN	14	20	27	23	25	13	--	12	15	12	10	11	8	6	5
GEBI	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--
HIAL	--	--	--	--	--	--	--	1	2	2	4	6	8	9	11
PTAQ	--	6	8	6	6	9	--	16	26	30	29	40	39	55	46
PYPI	--	--	--	--	--	--	--	--	--	1	1	--	--	--	--
XETE	--	--	--	--	--	--	--	--	--	1	1	1	1	1	1
Misc.	2	1	5	4	5	2	--	3	1	2	2	--	--	--	--



igure 16-3.—Tree and shrub cover.

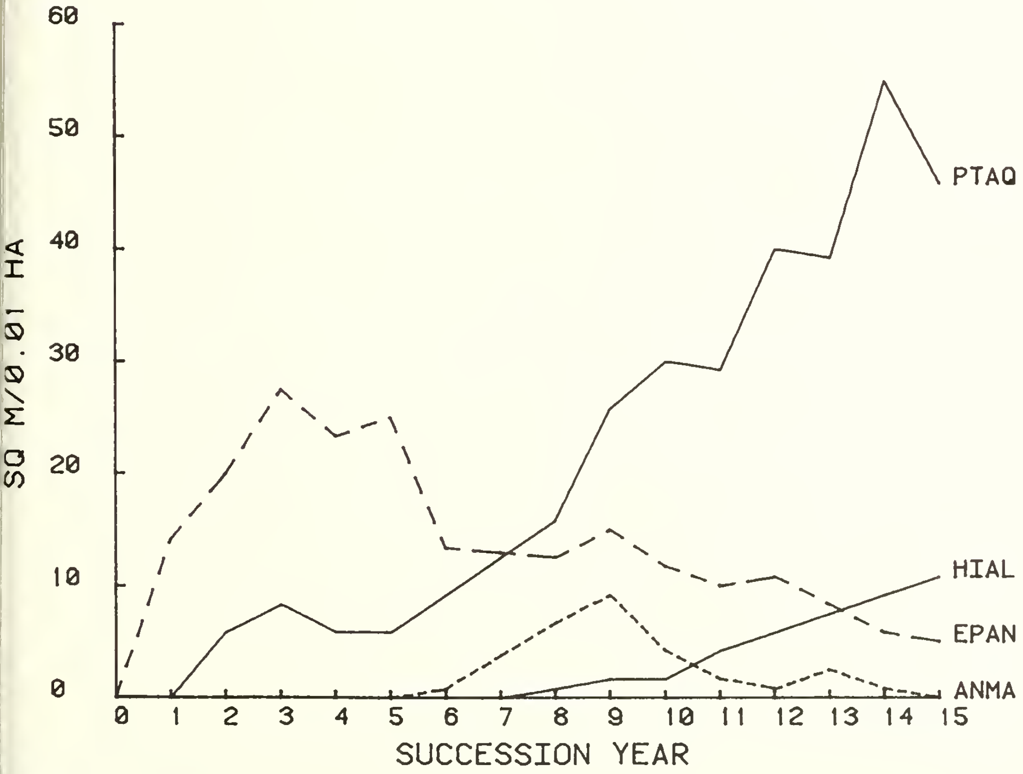


Figure 16-4.—Herb cover.

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Table 16-5.--Volume development of tree and shrub components (m^3/0.01 ha), fig. 16-5

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tree															
PIEN	--	--	--	--	--	--	--	0.4	0.5	1.0	1.0	2.1	3.3	3.7	4
PICO	--	--	--	--	--	3.0	--	22.3	45.9	76.6	124.6	168.5	272.9	281.1	378
PIMO	--	--	--	--	--	--	--	--	--	--	--	--	--	.6	
Shrub															
ALSI	--	--	--	--	10.8	17.0	--	38.5	30.2	21.1	18.5	42.6	87.9	89.9	197
PAMY	--	--	--	--	--	--	--	--	--	--	.3	.4	.8	.9	
RIVI	--	--	--	--	--	--	--	.5	.5	.7	1.1	.6	.9	1.3	1
RUPA	--	--	--	--	--	--	--	.1	.3	.5	.3	.2	1.2	1.6	1
SASC	0.1	2.6	5.2	8.1	21.0	8.6	--	17.1	11.2	15.3	9.8	18.3	29.2	22.3	33

Table 16-6.--Volume development of herb component (m^3/0.01 ha), fig. 16-6

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1
ANMA	--	--	--	--	--	0.4	--	2.1	2.7	1.4	0.8	0.2	0.8	0.2	--
APAN	--	--	--	--	--	--	--	--	--	--	--	1.2	--	.6	--
EPAN	2.7	7.5	11.2	10.9	12.9	6.6	--	5.7	7.9	8.4	6.7	7.3	5.6	3.8	3.
GEBI	--	.2	--	--	--	--	--	--	--	--	--	--	--	--	--
HIAL	--	--	--	--	--	--	--	.1	.1	.4	2.1	1.0	.4	3.7	2.
PTAQ	--	2.1	2.8	2.0	1.8	2.9	--	5.3	12.0	14.8	16.0	26.3	25.7	52.4	43.
PYPI	--	--	--	--	--	--	--	--	--	<.1	.2	--	--	--	--
XETE	--	--	--	--	--	--	--	--	--	.2	.2	.1	.1	<.1	.
Misc.	.2	.2	1.3	.9	1.4	.5	--	.8	.4	.3	.4	--	--	--	--

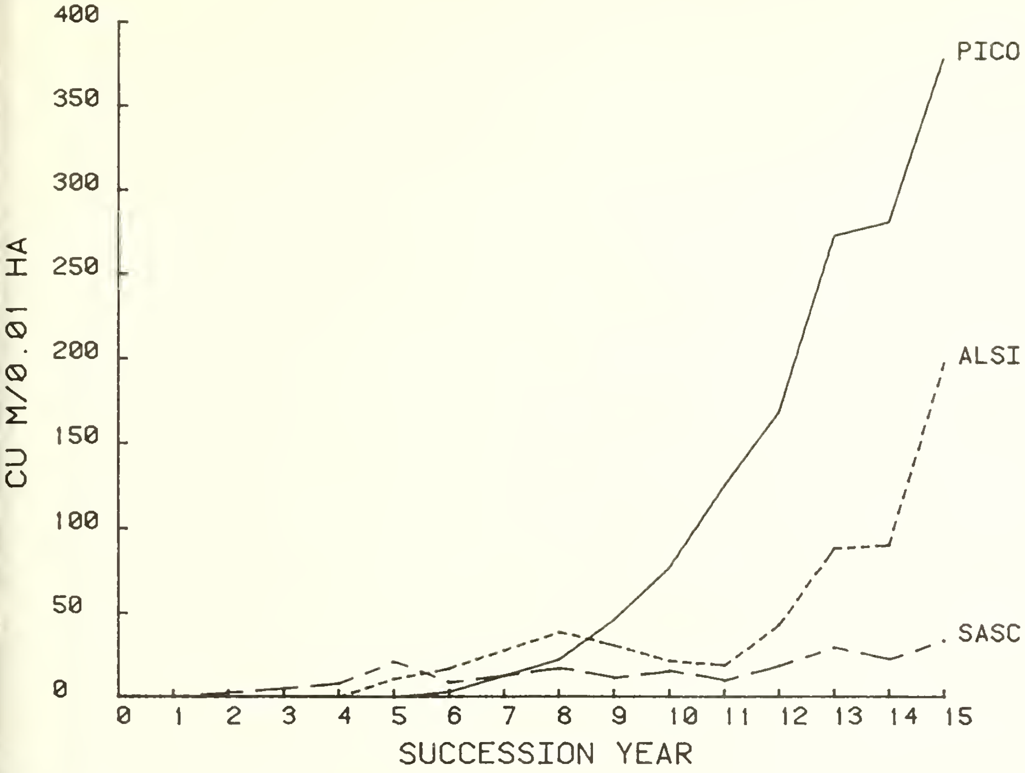

Figure 16-5.—Tree and shrub volume.

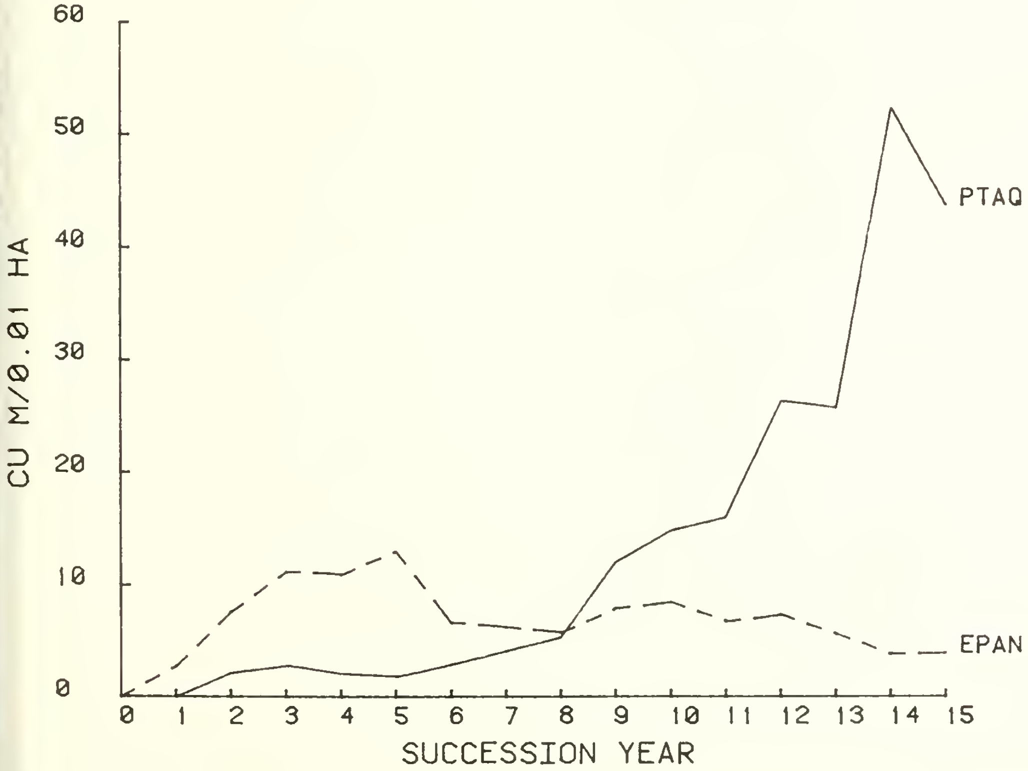

Figure 16-6.—Herb volume.

SUNDANCE BURN: 1802-16 Study Area SD-20

Site location and description: SE¼NW¼ sec. 29, T. 60 N., R. 2 W., BM; Elevation: 3,800 ft; Exposure: North (Az. 340°); Slope: 40%

Forest cover type and tree size class: Western white pine immature poletimber, 70 through 100% crown coverage

Reconstructed prefire forest stand:
Tree component: Conifer density: 32.0/0.01 ha; Average d.b.h.: 8.2 cm; Basal area: 2,384 cm^2/0.01 ha
Shrub component: SASC 100% (Shrub density: 3.6/0.01 ha);
Other species present: ACGL, PAMY, ROGY, RUPA, SPBE

Disturbance treatment:
Wildfire: September 2, 1967; Succession year 1:1968;
Fire intensity: -- Btu/sec/ft; Rate of spread: -- mi/h;
Fire severity: R-N index: 5-M; Overstory crown foliage: Consumed; Litter-duff: Consumed

Table 17-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 17-1

Life form component	Succession year													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Tree	--	--	--	--	--	<1	--	2	4	5	8	15	--	21
Shrub	9	28	35	36	31	36	--	70	40	47	47	47	--	150
Herb	36	44	31	30	33	27	--	38	42	48	45	52	--	54
Total veg.	45	72	65	66	64	63	--	110	86	100	99	114	--	225

Table 17-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 17-2

Life form component	Succession year													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Tree	--	--	--	--	--	0.1	--	1.5	3.2	5.9	9.4	20.5	--	43.9
Shrub	2.4	22.7	36.3	38.3	33.8	58.1	--	99.5	53.6	60.4	56.4	59.8	--	295.5
Herb	9.7	21.7	16.7	14.6	16.3	13.1	--	13.7	16.8	19.5	18.9	20.4	--	23.6
Total veg.	12.2	44.4	53.0	52.9	50.1	71.4	--	114.7	73.7	85.7	84.7	100.7	--	363.0

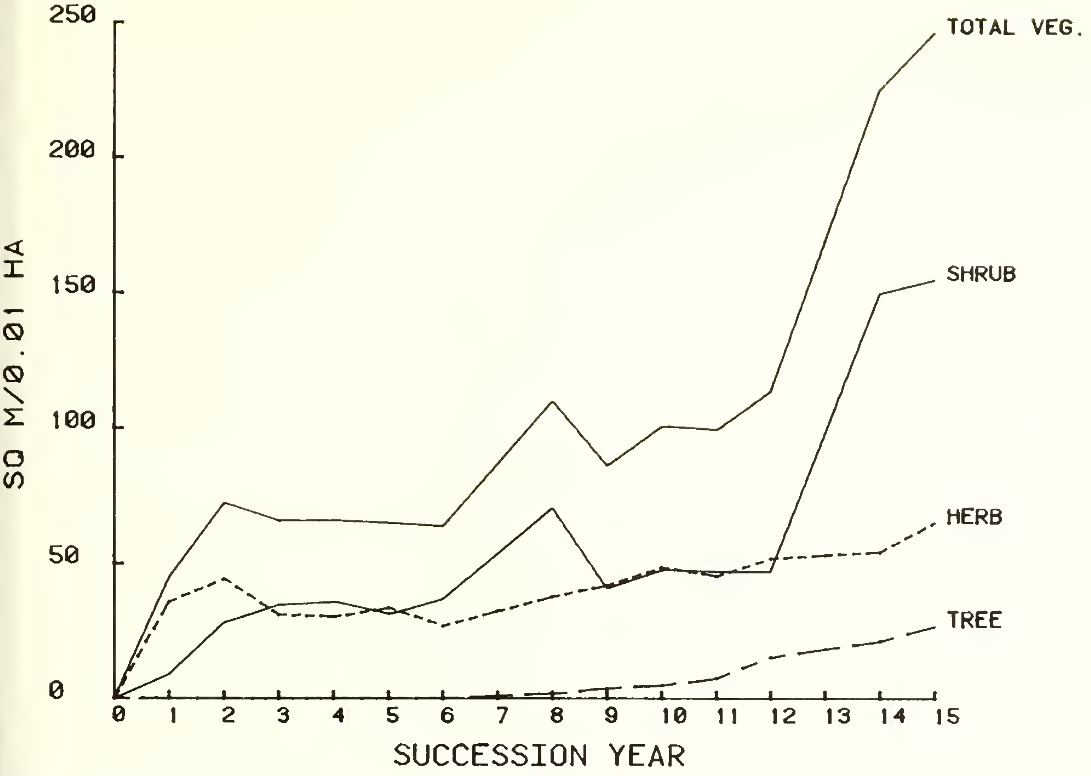

Figure 17-1.—Vegetative cover.

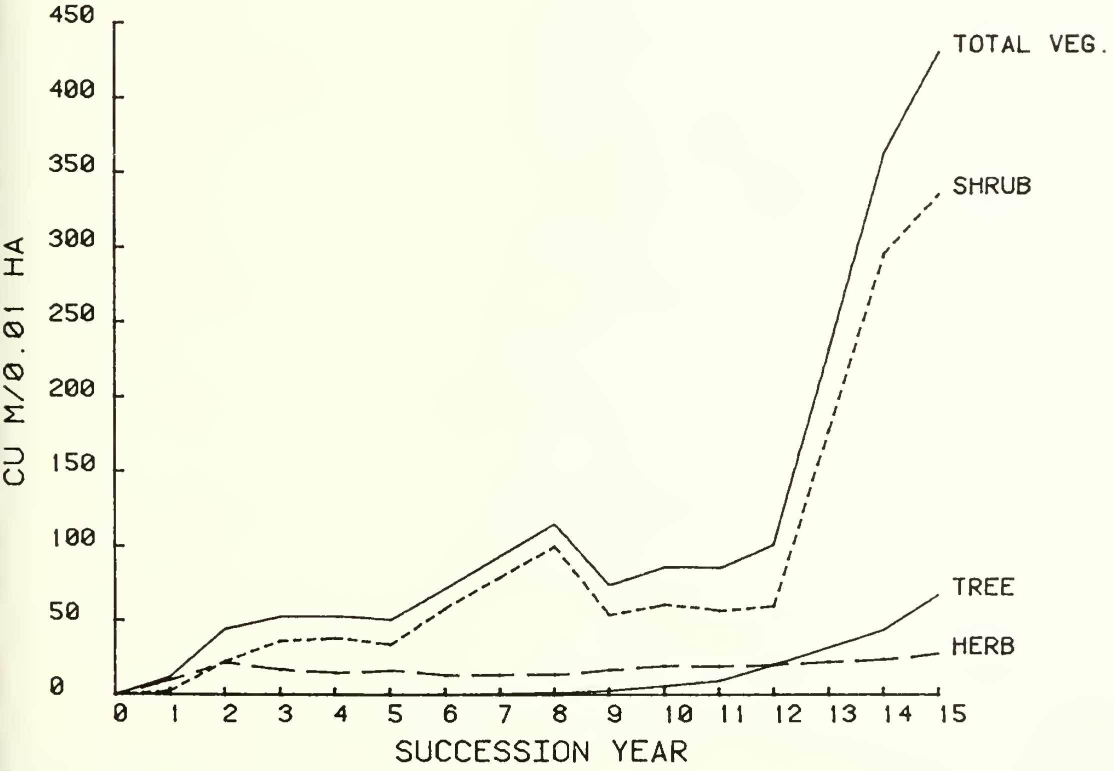

Figure 17-2.—Vegetative volume.

Table 17-3.--Cover development of tree and shrub components (m²/0.01 ha or %), fig. 17-3

Species	Succession year 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tree															
ABGR	--	--	--	--	--	--	--	--	1	--	2	5	--	6	7
BEPA	--	--	--	--	--	--	--	--	--	--	--	--	--	--	<1
LAOC	--	--	--	--	--	--	--	--	--	--	--	<1	--	1	1
PIEN	--	--	--	--	--	--	--	<1	1	1	1	2	--	2	2
PICO	--	--	--	--	--	<1	--	2	2	4	4	5	--	9	11
PIMO	--	--	--	--	--	--	--	--	--	1	1	2	--	3	4
POTRI	--	--	--	--	--	--	--	--	--	--	--	--	--	--	<1
PSME	--	--	--	--	--	--	--	--	--	--	--	<1	--	1	1
Shrub															
ALSI	--	--	--	--	--	--	--	--	--	1	9	12	--	86	93
PAMY	--	--	--	--	--	--	--	--	--	--	--	--	--	1	1
RUPA	3	7	6	2	5	4	--	12	10	16	11	10	--	16	27
SASC	6	21	28	33	26	32	--	59	31	31	25	25	--	46	34
SPBE	--	--	--	--	--	--	--	--	--	<1	1	--	--	1	--

Table 17-4.--Cover development of herb component (m²/0.01 ha or %), fig. 17-4

Species	Succession year 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
ANMA	--	--	--	--	1	1	--	1	5	5	3	2	--	1	--
ARLA	--	--	--	--	--	--	--	2	2	6	8	11	--	12	19
CAMI	--	--	--	--	--	--	--	--	--	--	--	1	--	2	2
CLUN	--	--	--	--	--	--	--	--	--	1	1	2	--	2	3
EPAN	33	39	29	19	25	17	--	12	15	8	8	7	--	6	4
HIAL	--	--	--	--	--	--	--	--	2	2	2	3	--	2	2
LICO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1
PTAQ	--	4	1	8	8	7	--	17	15	22	18	24	--	28	32
Misc.	2	1	1	2	--	2	--	6	2	4	3	2	--	1	--

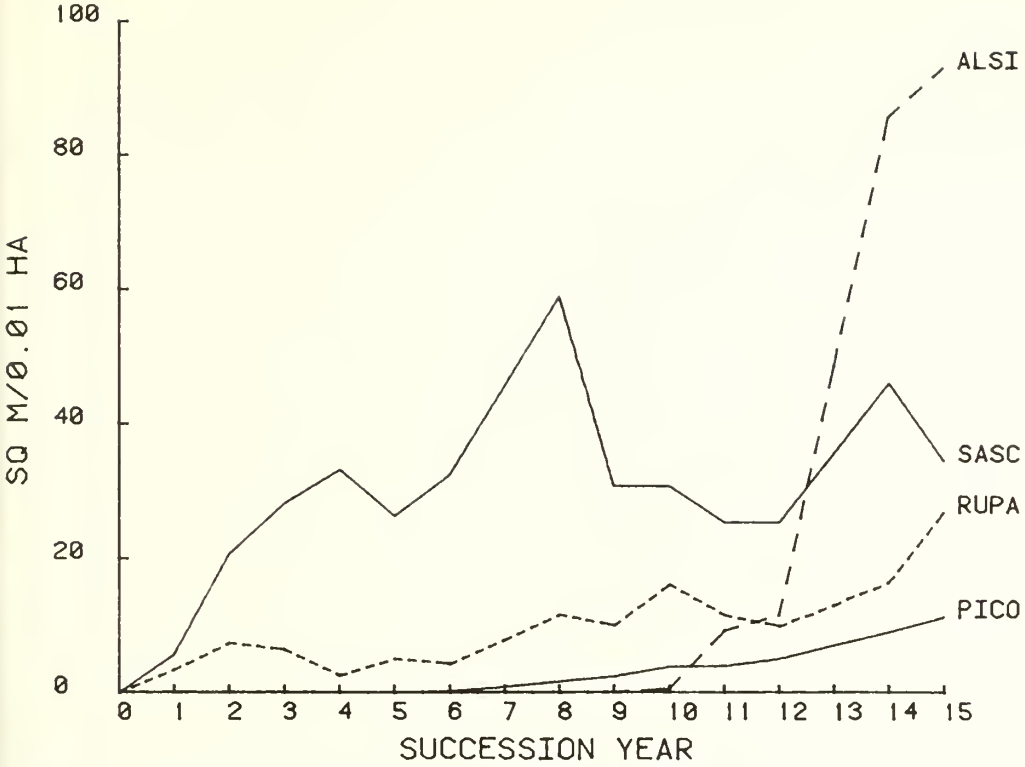

Figure 17-3.—Tree and shrub cover.

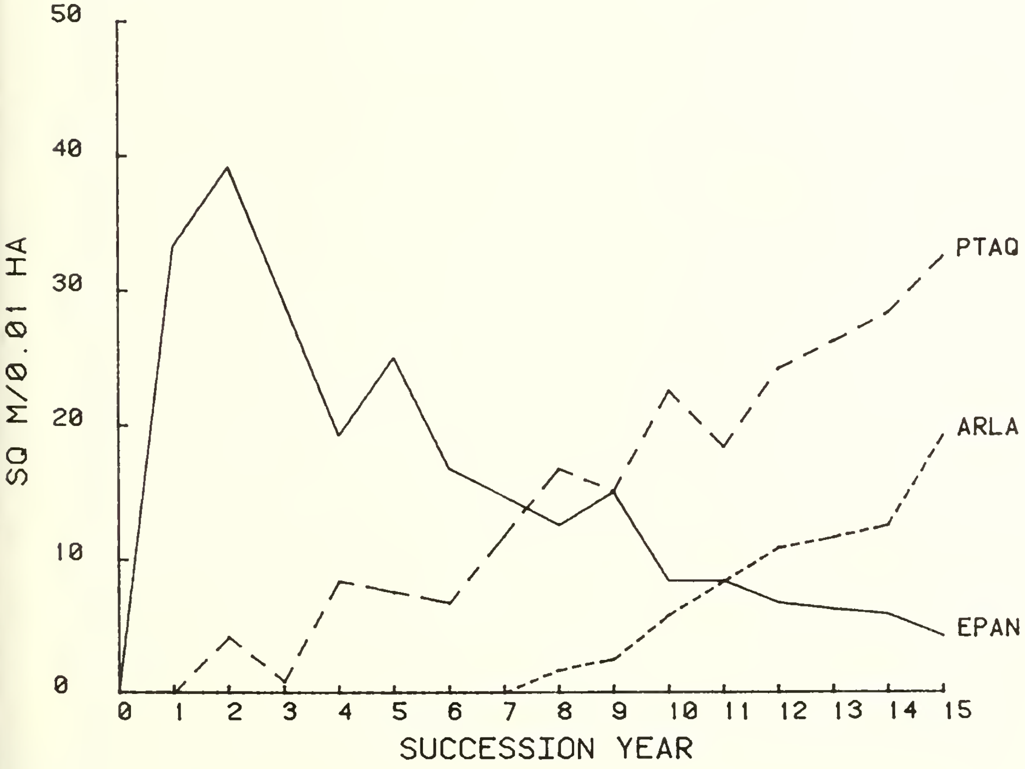

Figure 17-4.—Herb cover.

Table 17-5.--Volume development of tree and shrub components (m³/0.01 ha), fig. 17-5

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tree															
ABGR	--	--	--	--	--	--	--	--	0.4	--	1.0	5.0	--	7.5	10.4
BEPA	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.5
LAOC	--	--	--	--	--	--	--	--	--	--	--	.2	--	1.6	2.7
PIEN	--	--	--	--	--	--	--	0.1	.3	0.3	.5	1.5	--	2.0	2.3
PICO	--	--	--	--	--	0.1	--	1.3	2.5	5.4	7.4	12.0	--	27.1	40.4
PIMO	--	--	--	--	--	--	--	--	--	.3	.5	1.6	--	5.2	9.0
POTRI	--	--	--	--	--	--	--	--	--	--	--	--	--	--	<.1
PSME	--	--	--	--	--	--	--	--	--	--	--	.1	--	.4	.6
Shrub															
ALSI	--	--	--	--	--	--	--	--	--	.5	11.2	19.3	--	214.0	260.7
PAMY	--	--	--	--	--	--	--	--	--	--	--	--	--	.3	.3
RUPA	0.6	2.6	2.8	0.4	2.1	2.5	--	6.0	4.2	7.5	5.1	4.3	--	10.5	16.1
SASC	1.8	20.1	33.5	37.8	31.7	55.7	--	93.5	49.4	52.4	39.7	36.2	--	70.4	58.7
SPBE	--	--	--	--	--	--	--	--	--	<.1	.3	--	--	.3	--

Table 17-6.--Volume development of herb component (m³/0.01 ha), fig. 17-6

	Succession year														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
ANMA	--	--	--	--	0.3	0.4	--	0.4	1.7	1.7	1.4	0.9	--	0.3	--
ARLA	--	--	--	--	--	--	--	.2	.2	.5	1.1	1.2	--	2.1	2.9
CAMI	--	--	--	--	--	--	--	--	--	--	--	.4	--	.3	1.3
CLUN	--	--	--	--	--	--	--	--	--	<.1	<.1	.2	--	.1	.2
EPAN	9.4	19.6	16.1	9.9	13.7	9.6	--	4.8	7.4	4.1	4.3	3.9	--	3.0	2.6
HIAL	--	--	--	--	--	--	--	--	.4	.4	1.1	.8	--	.8	.1
LICO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	.8
PTAQ	--	1.9	.3	3.9	2.3	2.4	--	7.2	6.4	11.7	10.1	12.6	--	16.8	19.8
Misc.	.3	.2	.3	.8	--	.7	--	1.2	.8	1.0	.8	.5	--	.2	--

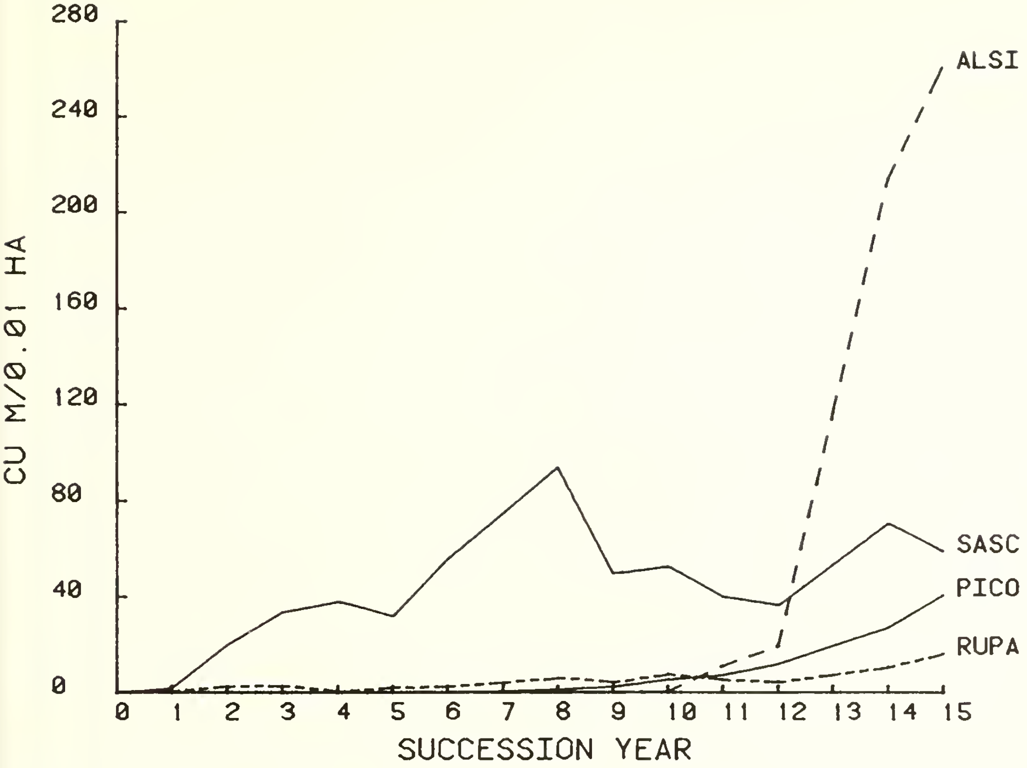

Figure 17-5.—Tree and shrub volume.

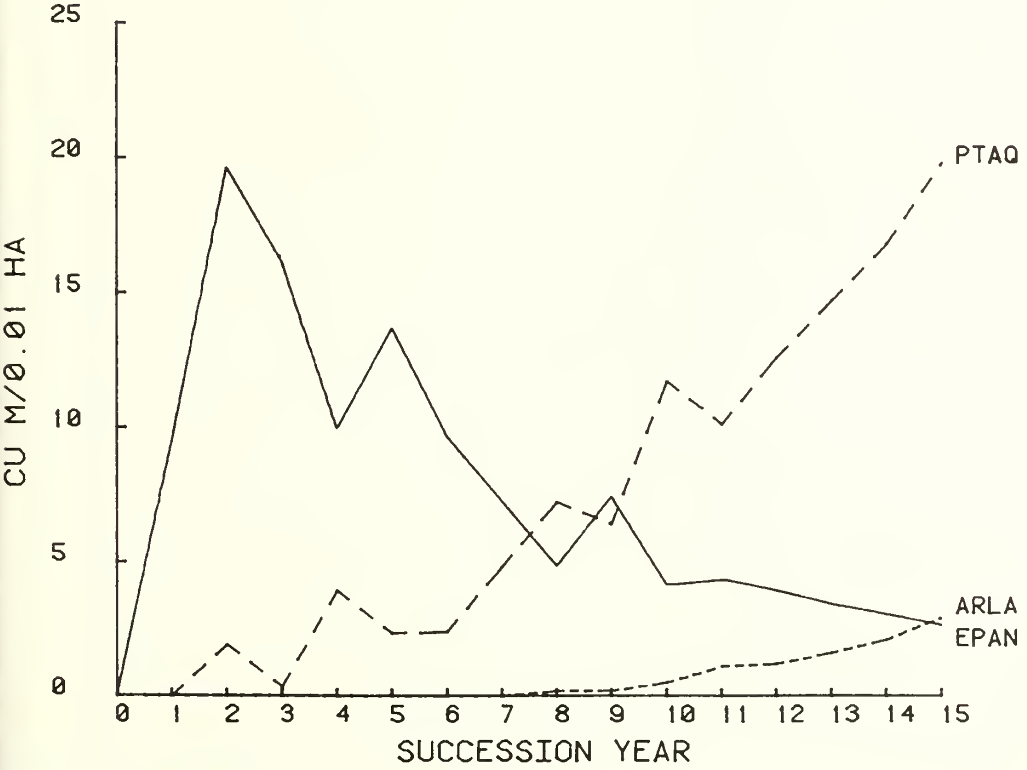

Figure 17-6.—Herb volume.

SUNDANCE BURN: 1802-16 Study Area SD-21

Site location and description: SW¼SE¼ sec. 20, T. 60 N., R. 2 W., BM; Elevation: 3,450 ft; Exposure: South (Az. 165°); Slope: 25%

Forest cover type and tree size class: Douglas-fir nonstocked, <10% crown cover

Reconstructed prefire forest stand:
Tree component: Conifer density: 1.6/0.01 ha; Average d.b.h.: 6.2 cm; Basal area: 54 cm²/0.01 ha
Shrub component: CESA 24%, PREM 32%, ROGY 1%, SASC 43% (Shrub density: 53.6/0.01 ha);
Other species present: AMAL, PAMY, RUPA, VAME

Disturbance treatment:
Wildfire: September 1, 1967 (1930 hrs); Succession year 1:1968;
Fire intensity: 3,400 to 22,500 Btu/sec/ft; Rate of spread: 1 to 6 mi/h;
Fire severity: R-N index: 5-M; Overstory crown foliage: Consumed; Litter-duff: Consumed

Table 18-1.--Successional development of vegetative cover (m²/0.01 ha or %), fig. 18-1

Life form component	Succession year 1	2	3	4	5	6
Tree	--	--	--	--	--	--
Shrub	63	66	96	124	160	114
Herb	32	46	36	37	35	32
Total veg.	95	112	132	162	195	147

Table 18-2.--Successional development of vegetative volume (m³/0.01 ha), fig. 18-2

Life form component	Succession year 1	2	3	4	5	6
Tree	--	--	--	--	--	--
Shrub	77.0	74.1	119.2	156.0	211.8	203.7
Herb	11.5	24.0	17.7	18.9	19.4	18.4
Total veg.	88.4	98.1	136.9	174.9	231.2	222.1

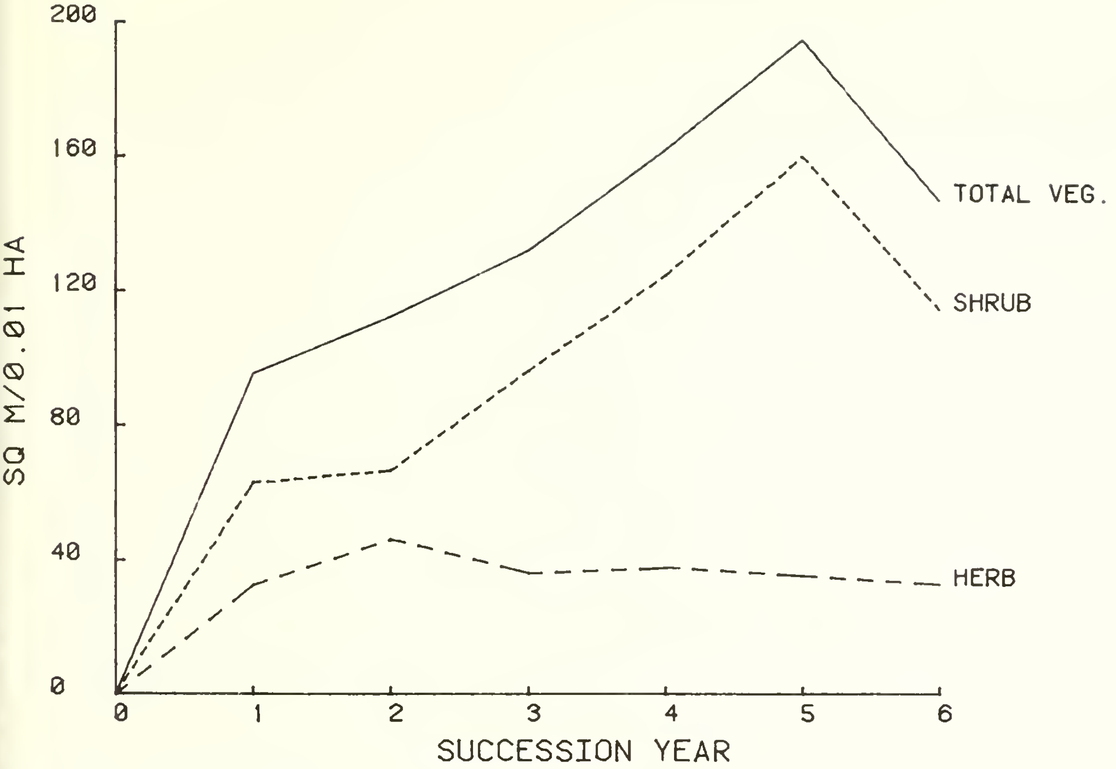

Figure 18-1.—Vegetative cover.

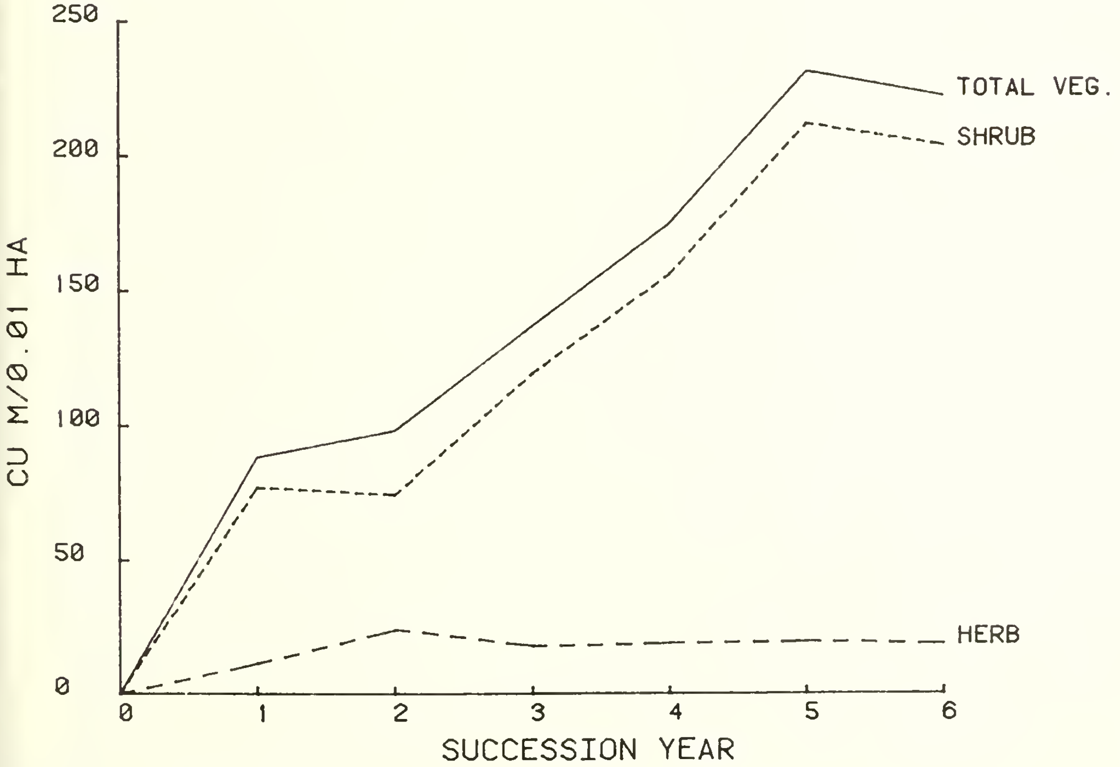

Figure 18-2.—Vegetative volume.

Table 18-3.--Cover development of shrub component (m^2/0.01 ha or %), fig. 18-3

	Succession year					
Species	1	2	3	4	5	6
CESA	5	15	32	69	95	45
PREM	7	6	6	3	4	9
ROGY	2	2	2	2	3	2
RUPA	14	20	21	22	31	16
SASC	35	24	35	28	27	42

Table 18-4.--Cover development of herb component (m^2/0.01 ha or %), fig. 18-4

	Succession year					
Species	1	2	3	4	5	6
APAN	1	1	1	1	3	1
CARU	--	--	2	1	1	1
CLUN	--	--	--	--	1	--
DIHO	1	1	--	2	2	2
EPAN	6	5	3	4	3	4
PTAQ	20	30	22	23	22	22
TRRE	--	4	--	--	--	--
Misc.	5	5	8	6	2	3

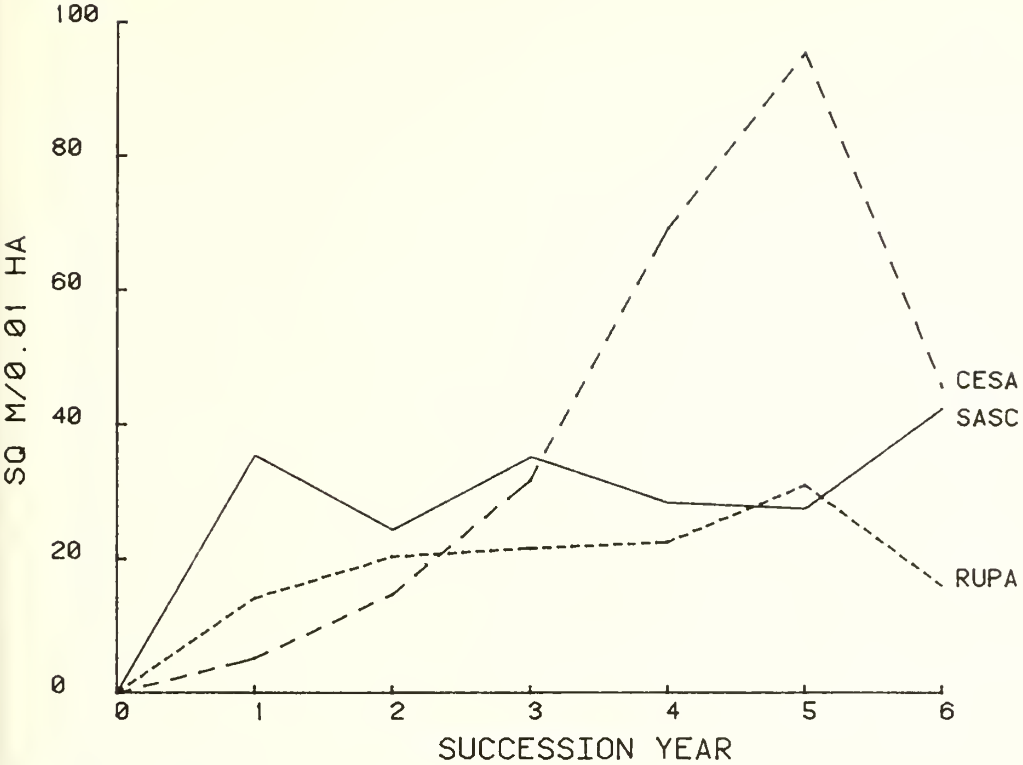

Figure 18-3.—Shrub cover.

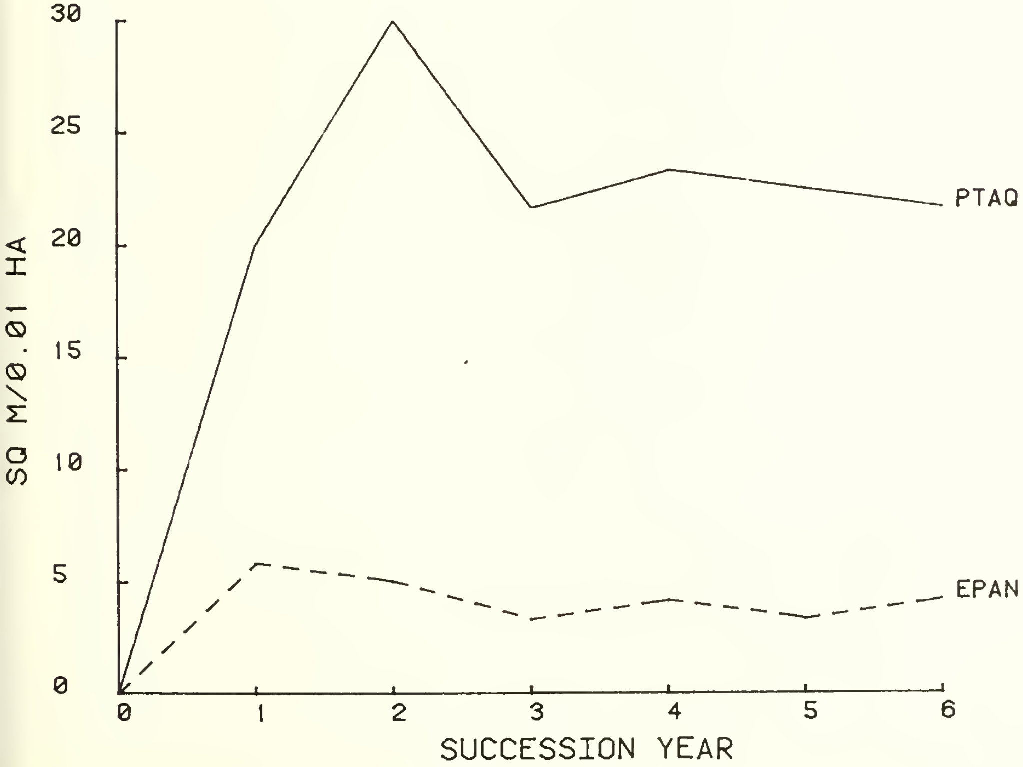

Figure 18-4.—Herb cover.

Table 18-5.--Volume development of shrub component (m^3/0.01 ha), fig. 18-5

	Succession year					
Species	1	2	3	4	5	6
CESA	1.7	8.8	22.8	68.1	118.7	44.5
PREM	5.3	5.1	5.0	3.3	3.7	11.6
ROGY	.3	.4	.6	.5	1.1	.8
RUPA	6.6	6.6	8.4	8.5	10.9	4.5
SASC	63.1	53.0	82.3	75.5	77.3	142.2

Table 18-6.--Volume development of herb component (m^3/0.01 ha), fig. 18-6

	Succession year					
Species	1	2	3	4	5	6
APAN	0.1	0.2	0.3	0.2	1.3	0.2
CARU	--	--	.5	.2	.3	.3
CLUN	--	--	--	--	<.1	--
DIHO	.1	.2	--	.4	.3	.3
EPAN	1.4	2.2	1.5	1.9	1.9	2.4
PTAQ	9.2	19.8	13.1	14.5	14.7	13.9
TRRE	--	.4	--	--	--	--
Misc.	.7	1.2	2.3	1.6	.8	1.2

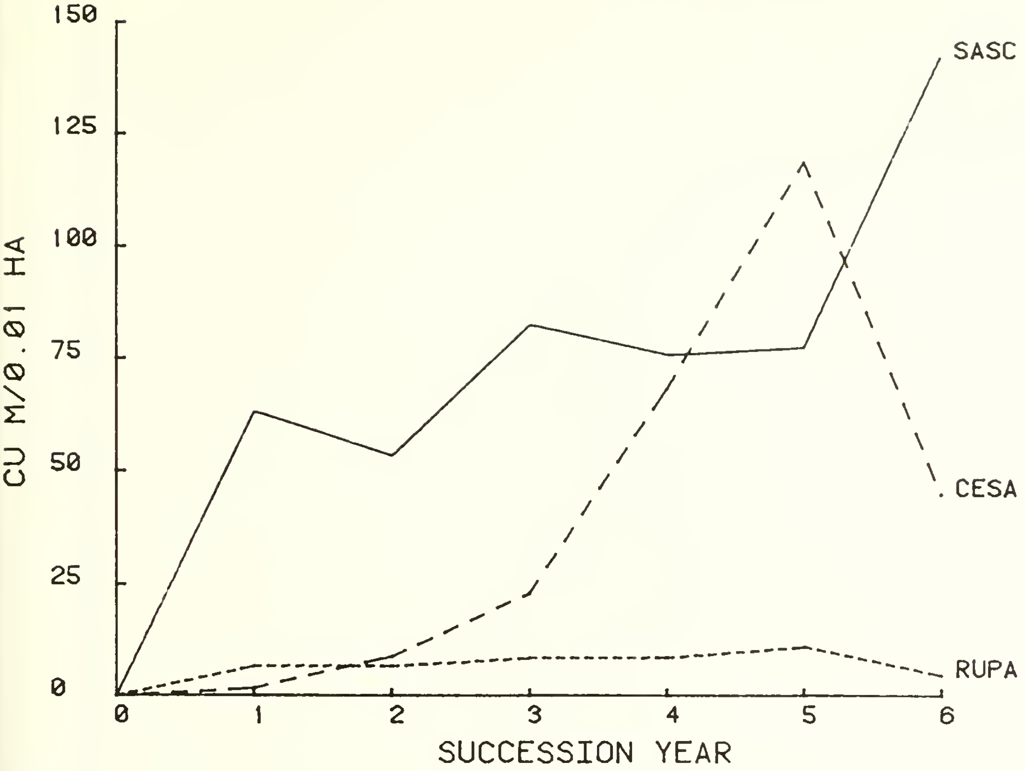

Figure 18-5.—Shrub volume.

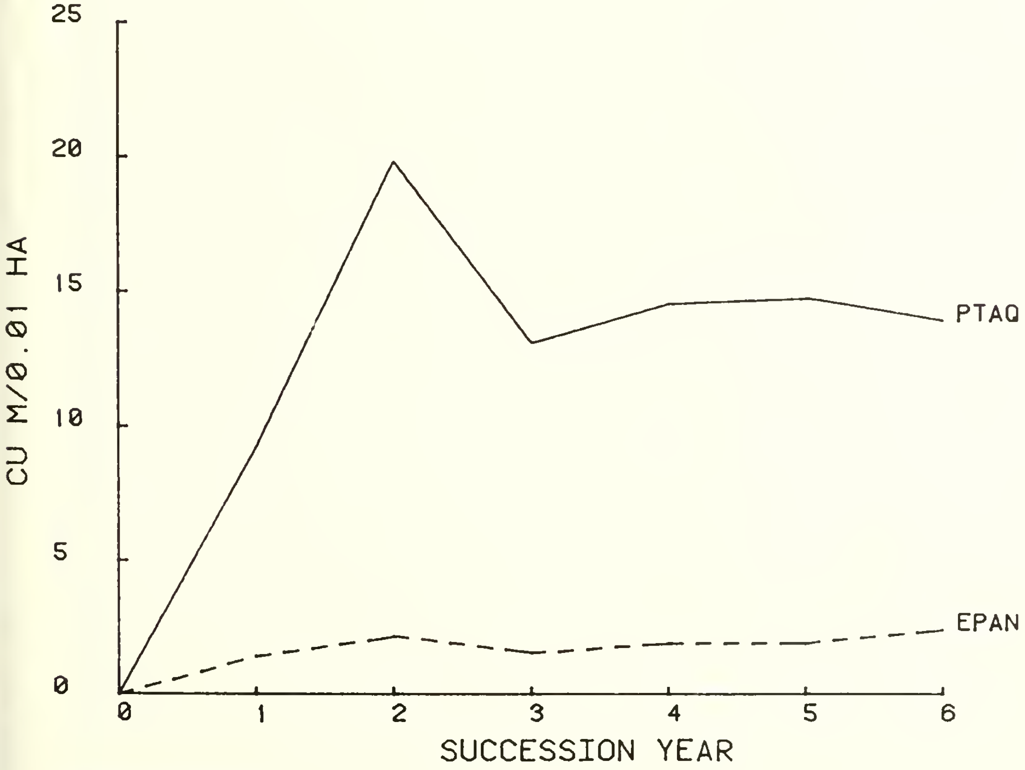

Figure 18-6.—Herb volume.

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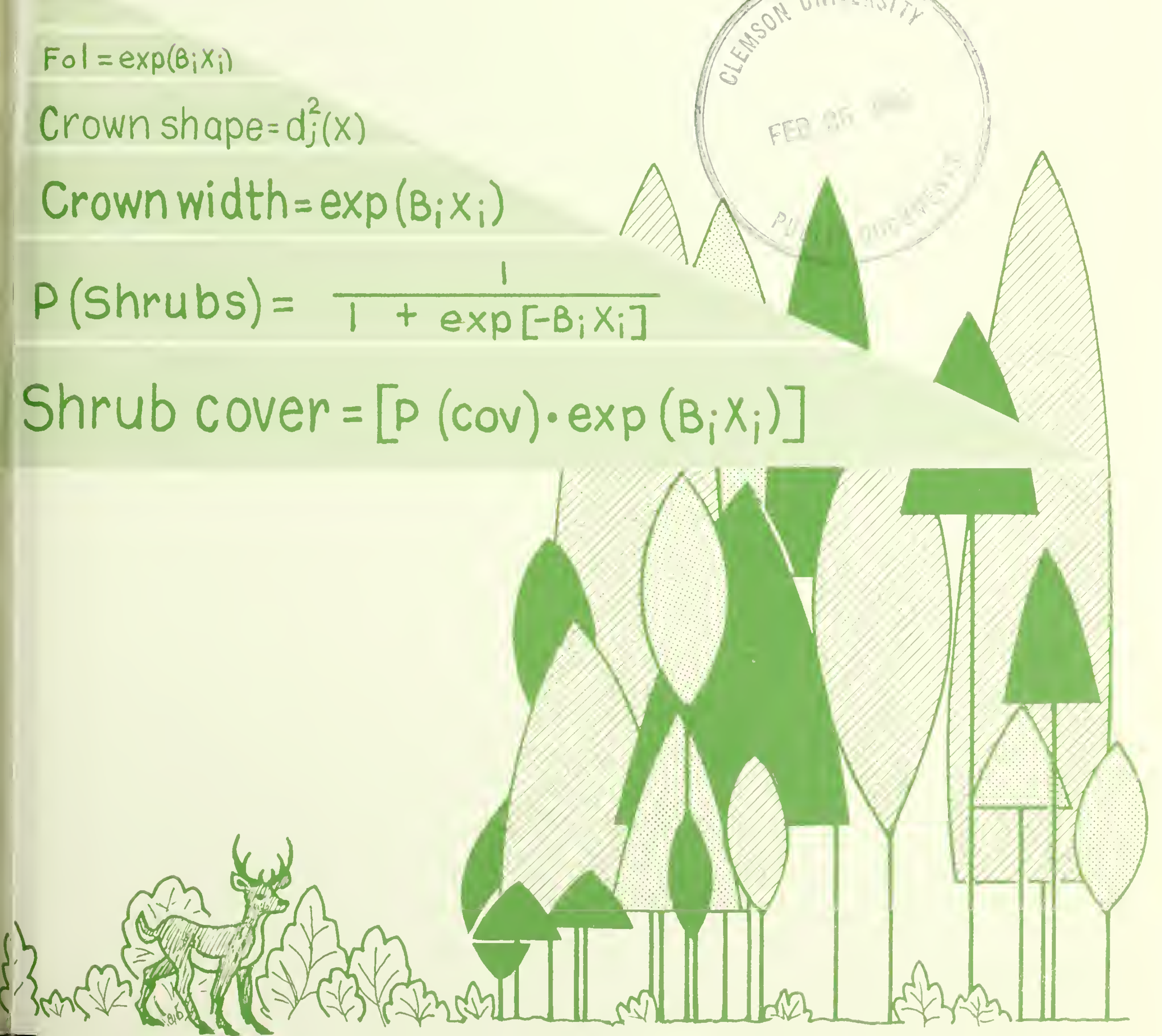
O tober 1985

COVER: A User's Guide to the CANOPY and SHRUBS Extension of the Stand Prognosis Model

Melinda Moeur

CLEMSON UNIVERSITY
FEB 25
PUBLIC DOCUMENTS


$Fol = \exp(B_i X_i)$
$\text{Crown shape} = d_j^2(X)$
$\text{Crown width} = \exp(B_i X_i)$
$P(\text{Shrubs}) = \frac{1}{1 + \exp[-B_i X_i]}$
$\text{Shrub cover} = [P(\text{cov}) \cdot \exp(B_i X_i)]$

THE AUTHOR

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This publication replaces a draft user's guide distributed in 1981 (Moeur and Scharosch 1981). Enhancements to the early version of the COVER and BROWSE programs are described herein. In addition, there are changes to several of the keyword names and formats linking the COVER extension to Version 5.0 of the Prognosis Model, as reported in the Prognosis Model User's Guide (Wykoff and others 1982):

Prognosis Model User's Guide		**COVER Extension User's Guide**	
Keyword		Keyword	
		COVER	Invoke the COVER extension (for either canopy or shrubs). field 1: Cycle to begin COVER predictions. field 2: Dataset reference number for output.
COVER	Invoke the COVER option in the shrub and cover extension. field 1: Method to be used to compute foliage biomass.	CANOPY	Compute crown cover statistics.
SHRUB	Invoke the BROWSE option of the shrub and cover extension. field 1: Number of years since stand was regenerated. field 2: Number of years shrub output will be printed. field 3: Habitat type code for processing SHRUB option.	SHRUBS	Compute shrub statistics. field 1: Number of years since stand disturbance. field 2: Habitat type code for processing SHRUBS option. field 3: Physiographic type code. field 4: Disturbance type code.

ACKNOWLEDGMENTS

Research leading to the understory development models incorporated in the COVER program resulted from cooperative studies between the Intermountain Research Station and the University of Idaho, College of Forestry, Wildlife and Range Sciences. University of Idaho cooperators who contributed to modeling of data and linkage to the Prognosis Model include Dr. Steven B. Laursen, Steve N. Scharosch, Dr. Charles R. Hatch, Dr. James A. Moore, Dr. James M. Peek, and Dr. Larry L. Irwin (now at University of Wyoming).

I am grateful to Dr. E. O. Garton, University of Idaho, for providing the data used to fit crown shape models. Special thanks also to Nezperce National Forest personnel George Bain and Susan Wise, Salmon River Ranger District silviculturist and wildlife biologist, respectively, for supplying stand data, silvicultural prescriptions, and advice in preparing the wildlife examples.

RESEARCH SUMMARY

The COVER extension to the Stand Prognosis Model predicts tree canopy closure, crown volume, crown profile area, and foliage biomass within vertical height classes, and the probability of occurrence, height, and cover of shrubs in forest stands. The model may be used to produce a descriptive summary of a stand at the time of inventory, or to project overstory and understory characteristics through time for natural and managed stands. This paper documents use of the COVER program, an adjunct to Version 5.0 of the Prognosis Model. Preparation of input, interpretation of output, program control, and model characteristics are described. Potential applications of COVER estimates to wildlife, hydrology, and insect pest modeling are presented.

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COVER: A User's Guide to the CANOPY and SHRUBS Extension of the Stand Prognosis Model

Melinda Moeur

INTRODUCTION

Forest managers in the Northern Rocky Mountains have extensively used the Prognosis Model for Stand Development (Stage 1973) to summarize current stand conditions, and to predict the future path of stand growth and the likely consequences of alternative management practices on stand development. The use of stand models like Prognosis need not be restricted to timber management applications. For example, forest managers must also consider how management practices may change the suitability of a stand for wildlife habitat, the composition of the understory, or the sequence of succession. The computer model described in this paper, known as COVER, extends Prognosis by modeling the development of tree crowns and understory vegetation. COVER provides three types of information: a description of the amount of cover and foliage in the tree canopy by height class; the height and cover of shrubs, forbs, and grasses in the understory; and a summary of overstory and understory cover and biomass for the stand.

COVER offers two options that can be run separately or together: CANOPY controls predictions of values related to tree crowns; SHRUBS controls predictions of understory characteristics. Possible applications of the COVER model include examining the likely effects of silvicultural treatments on:

- forest stand characteristics important to wildlife, such as thermal cover and hiding cover, browse production, and the interactions of shrubs and trees that determine vertical and horizontal stand structure.
- dynamics of the shrub community affecting stand succession and competition with regeneration.
- vertical crown form and foliage distribution important to feeding and dispersal patterns of insect pests, such as the western spruce budworm.
- canopy cover and ground cover development which affect the hydrologic characteristics of a stand following harvest.

This manual is intended to be a companion publication to the Prognosis Model User's Guide (Wykoff and others 1982). The research described here is based on the idea that management prescriptions which affect nonvegetation ecosystem components can be compared and evaluated by examining simulated changes in the major vegetation components. Wykoff and others (1982) have summed up this philosophy, which guides our research:

> Consequences for streamflow from the forest, for wildlife populations, and for pest populations that inhabit the forest, as well as the capability of the forest to yield timber or provide recreation—all depend on how the dominant vegetation changes and is changed. Unfortunately, yield forecasts have traditionally emphasized the merchantable harvest that might be obtained, either immediately or as a sequence of yields obtainable at intervals of time into the future. Volumes of merchantable timber have been the most common units of measure because timber products have usually been the primary reason for investment. As other uses for the forest become more important, however, growth forecasts need to be stated in more fundamental descriptions of the future forest stand. Too often, evaluation of tradeoffs among conflicting activities or objectives for use of forest resources has been hampered by lack of sensitivity of the forecasts to the interactions among ecosystem components. One objective for development of the Stand Prognosis Model is to so characterize stand dynamics that the model will provide a sensitive basis for representing interactions involving the tree species.

COVER can provide a detailed picture of the vegetative structure of a single stand through time under different silvicultural prescriptions. By linking to the Parallel Processing version of Prognosis (Crookston 1985), COVER can also model long-term, large-scale changes for groups of stands arranged in time and space. As such, it may be a useful tool for enhancing forest management decisions that concern nontimber ecosystem components. This publication begins with a description of the information produced by the model and instructions for making the program run. There follows a discussion of the biological behavior of the individual submodels and a final section dealing with potential applications.

Range of Predictions

The models comprising COVER are parameterized with data collected in the Inland Northwest and Northern Rocky Mountain forests. The user should determine if the range of species and site conditions for which predictions are made are applicable to the local situation.

Submodels for the CANOPY option predict conifer crown width, crown shape, and foliage biomass. Equations for crown width and foliage biomass are derived from data on 370 trees on 14 sites in northern Idaho and western Montana (Moeur 1981; Brown 1978). Sampled stand basal area ranges from 1 to 426 ft^2/acre. Open-grown trees and trees that were obviously damaged or heavily defoliated were not sampled. Data for the crown shape models are from 9,800 trees on 12 sites in western Montana, the Blue Mountains of eastern Oregon, and the University of Idaho forest near Moscow, ID (Langelier and Garton in press a).

The understory portion of COVER includes models that predict probability of occurrence, height, and cover of individual shrub, forb, grass, and fern species (Scharosch 1984; Laursen 1984). Understory data are from over 10,000 1/300-acre plots on 500 stands in Douglas-fir, grand fir, western redcedar, western hemlock, and subalpine fir habitat types. Stands were measured between 3 and 40 years following major stand disturbance. These data are from northern Idaho, northeastern Washington, and northwestern Montana (Colville, Panhandle, Kootenai, Lolo, and Clearwater National Forests), to central and southern Idaho and northwestern Wyoming (Nezperce, Boise, Payette, and Targhee National Forests) (Ferguson and others [in press]). In addition, Irwin and Peek (1979) fit models for twig production and dormant season shrub biomass on a subset of the data (grand fir, cedar, and hemlock types).

Current data sources make the COVER predictions most applicable to the Northern Region (R-1), and portions of the Intermountain (R-4) and Pacific Northwest (R-6) Regions of the Forest Service. The user should exercise caution in extending predictions outside these geographic areas.

Data Requirements

Information needed to run COVER consists of the minimum Prognosis Model input—the inventory design used to measure the stand, a list of sampled trees for which species, diameter, and plot identification have been recorded, and values for slope, aspect, elevation, habitat type, and forest location recorded on the STDINFO card (Wykoff and others 1982). If the SHRUBS option is used, time since stand disturbance, type of disturbance, and physiographic position are required.

Understory predictions are improved if field measurements of shrub height and cover are available for calibrating portions of the shrub models. These data are only supplementary, and both the CANOPY and SHRUBS options will execute without them. The keywords section discusses how to enter calibration information.

INFORMATION PRODUCED

The COVER program normally produces three displays—one describing the structure of tree crowns, another describing the composition of the understory, and a third summarizing overstory and understory cover and biomass. The user may insert keywords to turn off the printing of any of the displays.

As you proceed through this publication, the same stand used in the Prognosis Model User's Guide (Wykoff and others 1982) will be used to develop examples. The stand (S248112) is on the St. Joe National Forest. It is 57 years old at the inventory date, positioned on a northwest aspect, 30 percent midslope, at 3,400 feet of elevation, and is a *Tsuga heterophylla/Clintonia uniflora* habitat type. Values presented here result from the COVER extension combined with Version 5.0 of the Inland Empire Prognosis Model and Version 1.0 of the Regeneration Establishment Model (Ferguson and Crookston 1984). Four COVER extension keywords (COVER, CANOPY, SHRUBS, and END) inserted into the Prognosis Model runstream in figure 1 produce the example canopy and shrub displays.

Canopy Cover Statistics Display

The Canopy Cover Statistics display is the first of the three COVER displays (fig. 2). It is produced when the CANOPY option is specified. To give the user a feel for the vertical profile of the conifer component of the stand, crown cover values are partitioned by 10-foot height classes.

Trees per acre.—The number of trees per acre whose total heights fall within a given height class.

Canopy closure.—The percentage of ground area covered by the projections of individual crowns of trees whose total heights fall within a given height class (fig. 3a).

Crown profile area.—The area in square feet per acre within vertical height classes occupied by crown profiles, represented by the sum of lateral areas of crown profile sections within height classes (fig. 3b). Crown profile area may be thought of as a foliage-height profile, or the view one would have if the stand were "squashed flat" in a vertical plane.

```
STDIDENT
S248112  PROGNOSIS WITH COVER EXTENSION - USER'S MANUAL EXAMPLE STAND
COMMENT
  THE PRESCRIPTION CALLS FOR IMMEDIATE REMOVAL OF EXCESS TREES,
  A COMMERCIAL THINNING AT AGE 90 TO REMOVE LODGEPOLE AND LARCH,
  A SHELTERWOOD REGENERATION TREATMENT AT AGE 120 FAVORING GRAND FIR
  AND DOUGLAS-FIR, AND AN OVERWOOD REMOVAL AT AGE 130.
END
DESIGN                                        11.0       1.0
STDINFO         18.0     570.0      57.0       8.0       3.0      34.0
INVYEAR       1977.0
NUMCYCLE        10.0
THINPRSC      1980.0     0.999
SPECPREF      2010.0       2.0     999.0
SPECPREF      2010.0       7.0    9999.0
THINBTA       2010.0     157.0
SPECPREF      2040.0       3.0    -999.0
SPECPREF      2040.0       4.0     -99.0
THINBTA       2040.0      35.0
ESTAB         2037.0
END
COVER
CANOPY
SHRUBS          57.0     570.0        3.
END
TREEDATA         5.0
   1      248112       0101   011LP 11510   0734   00111     0  0
   2      248112       0101   031DF 001     0026   00222     0  0
   3      248112       0102   011WH 06523   0308   00111     0  0
   4      248112       0102   011L  07906   0753   00111     0  0
   5      248112       0102   016L  346            10322     0  0
   6      248112       0103   011L  08007   0633   73222     0 56
   7      248112       0103   011GF 06220   0385   00111     0  0
   8      248112       0103   011L  084       54   00111     0  0
   9      248112       0103   011LP 09511   0603   00111     0  0
  10      248112       0104   011DF 040     0203   00111    50  0
  11      248112       0104   011L  08212   0655   50111     0  0
  12      248112       0105   011DF 012     0116   00222    42  0
  13      248112       0105   011DF 019     0135   00222    47  0
  14      248112       0105   015LP 072            11322     0  0
  15      248112       0105   031GF 001     0037   00222     0  0
  16      248112       0105   011GF 05309   0277   00111     0  0
  17      248112       0106   011DF 10010   0654   00111     0  0
  18      248112       0106   011GF 06112   0388   00111     0  0
  19      248112       0106   011DF 12716   0674   00111     0  0
  20      248112       0107                          800
  21      248112       0108   011LP 09605   0603   00222     0  0
  22      248112       0108   011DF 10409   0555   74222     0 49
  23      248112       0108   011LP 085       03   00111     0  0
  24      248112       0109   011GF 10910   0657   00111     0  0
  25      248112       0109   011DF 09418   0604   00111     0  0
  26      248112       0110   011C  03206   0175   00222    32  0
  27      248112       0110   011C  001     0027   00222     0  0
  28      248112       0110   011C  05810   0287   00111     0  0
  29      248112       0110   011C  05010   0253   00111    37  0
  30      248112       0111   011GF 06614   0307   00111     0  0
  31                   -999
PROCESS
STOP
```

Figure 1.—Keyword and tree record file used to project stand S248112 using the combined Prognosis Model and COVER extension.

```
                         STAND GROWTH PROGNOSIS SYSTEM          VERSION 5.0 -- INLAND EMPIRE

STAND ID:  S248112    MANAGEMENT CODE:  NONE    PROGNOSIS WITH COVER EXTENSION - USER'S MANUAL EXAMPLE STAND

------------------------------------------------ CANOPY COVER STATISTICS --------------------------------------------------

                                                   -----------------------------
                                                    ATTRIBUTE BY 10' HEIGHT CLASS
                                                   -----------------------------

                         TREES -- TREES PER ACRE
                         COVER -- PERCENTAGE OF CANOPY CLOSURE CONTRIBUTED BY TREES IN HEIGHT CLASS
                          AREA -- CROWN PROFILE AREA (SQ.FT. PER ACRE)
                        VOLUME -- CROWN VOLUME (CU.FT. PER ACRE X 100)
                       BIOMASS -- FOLIAGE BIOMASS (LBS. PER ACRE)


------------------------------------------------------------------------------------------------------------------------------------------------
                                                                STAND HEIGHT CLASS
                0.0-   10.1-   20.1-   30.1-   40.1-   50.1-   60.1-   70.1-   80.1-   90.1-  100.1-  110.1-  120.1-  130.1-  140.1-  150.1+
YEAR           10.0'   20.0'   30.0'   40.0'   50.0'   60.0'   70.0'   80.0'   90.0'  100.0'  110.0'  120.0'  130.0'  140.0'  150.0'              TOTAL
------------------------------------------------------------------------------------------------------------------------------------------------
1977
       TREES     220     131     111      39       0      41      29      17       0       0       0       0       0       0       0       0      590
       COVER      22      14      26       7       0       6       7       2       0       0       0       0       0       0       0       0       84
        AREA    2639   11868    5536    2070    4209    5480    2038     334       0       0       0       0       0       0       0       0    34173
      VOLUME     195     788     272     123     277     347     116      13       0       0       0       0       0       0       0       0     2130
     BIOMASS     593    2823    1254     338     622     886     210      16       0       0       0       0       0       0       0       0     6742

1977:POST-THIN
       TREES      11      30     111      39       0      27      29      17       0       0       0       0       0       0       0       0      264
       COVER      21       3      26       7       0       3       7       2       0       0       0       0       0       0       0       0       69
        AREA    1225    9871    5536    1478    3204    4730    2038     334       0       0       0       0       0       0       0       0    28416
      VOLUME     153     681     272      77     194     305     116      13       0       0       0       0       0       0       0       0     1811
     BIOMASS     483    2635    1254     251     449     768     210      16       0       0       0       0       0       0       0       0     6066

1987
       TREES       2       8      25      83      60       0      17      37      11       0       0       0       0       0       0       0      244
       COVER       0       3       4      25      20       0       2       9       1       0       0       0       0       0       0       0       65
        AREA     152    9462   10040    4990    1661    3928    4401    2025     239       0       0       0       0       0       0       0    36897
      VOLUME      22     966     668     271      89     258     316     118      10       0       0       0       0       0       0       0     2719
     BIOMASS      61    3194    2460     943     237     614     754     221       9       0       0       0       0       0       0       0     8493

1997
       TREES       0       6       2      31      78      47       2      15      34       9       0       0       0       0       0       0      224
       COVER       0       2       1       7      32      21       1       2      10       1       0       0       0       0       0       0       76
        AREA       2    7105   11698    9158    5356    2069    3080    2163    1141     174       0       0       0       0       0       0    41946
      VOLUME       0     978    1185     682     354     167     292     186      66       8       0       0       0       0       0       0     3917
     BIOMASS       0    2408    3384    1898     966     483     802     391      80       7       0       0       0       0       0       0    10418

2007
       TREES       0       0       6      14      30      53      42      16       5      33       5       0       0       0       0       0      204
       COVER       0       0       1       3      12      26      26       5       1      10       1       0       0       0       0       0       85
        AREA       2    3513   12374   11483    8574    5163    2175    2665    1642     790      43       0       0       0       0       0    48423
      VOLUME       0     638    1671    1144     721     351     171     290     163      47       2       0       0       0       0       0     5198
     BIOMASS       0    1155    3894    2936    1694     868     442     784     340      56       1       0       0       0       0       0    12171
```

Figure 2.—The canopy cover statistics display is produced when the CANOPY keyword is present in the runstream.

2007:POST-THIN																	
TREES	0	0	0	9	26	50	42	8	2	20	0	0	0	0	0	0	157
COVER	0	0	0	2	11	26	26	4	0	7	0	0	0	0	0	0	78
AREA	0	3508	12119	11212	8485	5090	1440	858	392	69	1	0	0	0	0	0	43172
VOLUME	0	638	1651	1131	718	348	129	157	71	8	0	0	0	0	0	0	4852
BIOMASS	0	1154	3831	2869	1682	852	395	560	253	27	0	0	0	0	0	0	11623
2017																	
TREES	0	0	0	0	19	16	52	32	7	9	12	0	0	0	0	0	147
COVER	0	0	0	0	5	11	33	26	5	2	6	0	0	0	0	0	87
AREA	0	1526	11392	13226	11036	8526	5393	1651	704	309	59	0	0	0	0	0	53821
VOLUME	0	339	1934	1763	1197	795	421	164	132	59	13	0	0	0	0	0	6817
BIOMASS	0	410	3515	3588	2278	1463	872	469	461	208	48	0	0	0	0	0	13312
2027																	
TREES	0	0	0	0	0	20	19	43	22	13	15	5	0	0	0	0	136
COVER	0	0	0	0	0	7	13	33	21	9	5	4	0	0	0	0	91
AREA	0	55	8324	12536	12670	10210	7725	4863	1683	455	160	22	0	0	0	0	58704
VOLUME	0	14	1682	1993	1624	1148	759	461	201	72	10	0	0	0	0	0	7965
BIOMASS	0	10	2354	3257	3032	1956	1372	1081	608	238	30	1	0	0	0	0	13937
2037																	
TREES	0	0	0	0	0	15	13	15	31	27	10	12	3	0	0	0	126
COVER	0	0	0	0	0	5	9	13	30	23	7	5	3	0	0	0	94
AREA	0	0	4645	11071	13303	11677	9643	6992	3813	1313	456	133	5	0	0	0	63051
VOLUME	0	0	1029	2020	2077	1593	1160	684	341	184	82	17	0	0	0	0	9186
BIOMASS	0	0	1028	2871	3489	2525	1781	1108	724	544	258	54	0	0	0	0	14381
2037:POST-THIN																	
TREES	0	0	0	0	0	0	1	7	5	3	5	12	3	0	0	0	35
COVER	0	0	0	0	0	0	0	1	1	2	3	5	3	0	0	0	14
AREA	0	0	153	722	976	1418	1537	1308	1187	859	407	119	5	0	0	0	8692
VOLUME	0	0	32	129	155	213	204	147	160	159	77	16	0	0	0	0	1292
BIOMASS	0	0	39	220	269	388	410	344	450	506	254	53	0	0	0	0	2933
2047																	
TREES	2192	37	0	0	0	0	0	1	5	5	2	12	6	1	0	0	2261
COVER	11	2	0	0	0	0	0	0	1	2	2	6	4	1	0	0	29
AREA	3380	45	575	972	1504	1623	1434	1492	1364	884	474	194	47	0	0	0	13991
VOLUME	51	4	117	176	251	238	181	214	239	162	84	25	2	0	0	0	1744
BIOMASS	209	11	282	475	688	677	531	796	984	667	349	109	9	0	0	0	5788
2057																	
TREES	2873	185	0	0	0	0	0	0	1	9	1	2	15	3	0	0	3090
COVER	28	9	0	0	0	0	0	0	0	2	2	2	8	4	0	0	55
AREA	11411	1347	540	967	1558	1772	1709	1535	1477	1315	827	441	162	34	0	0	25095
VOLUME	248	38	117	192	290	296	252	202	227	244	155	79	17	0	0	0	2357
BIOMASS	771	101	273	506	837	885	793	720	830	901	577	295	62	1	0	0	7551
2067																	
TREES	1696	603	91	0	0	0	0	0	0	1	9	2	12	4	3	0	2421
COVER	26	31	7	0	0	0	0	0	0	0	2	3	7	3	5	0	85
AREA	17479	8596	1260	937	1479	1883	1828	1593	1856	1606	1027	588	275	107	16	0	40530
VOLUME	484	303	153	199	292	346	295	226	320	304	181	88	26	4	0	0	3222
BIOMASS	1377	760	338	431	679	847	755	594	1095	1081	615	289	78	12	0	0	8950
2077																	
TREES	997	593	249	45	5	0	0	0	0	0	5	4	2	15	0	3	1921
COVER	23	38	22	6	1	0	0	0	0	0	1	2	3	10	1	5	111
AREA	16734	17017	6011	1500	1244	1898	1893	1793	1720	1686	1430	925	522	217	67	2	54662
VOLUME	514	722	334	220	242	385	344	289	260	287	273	166	84	21	1	0	4142
BIOMASS	1584	1703	925	425	503	842	773	681	698	862	865	530	270	63	3	0	10728

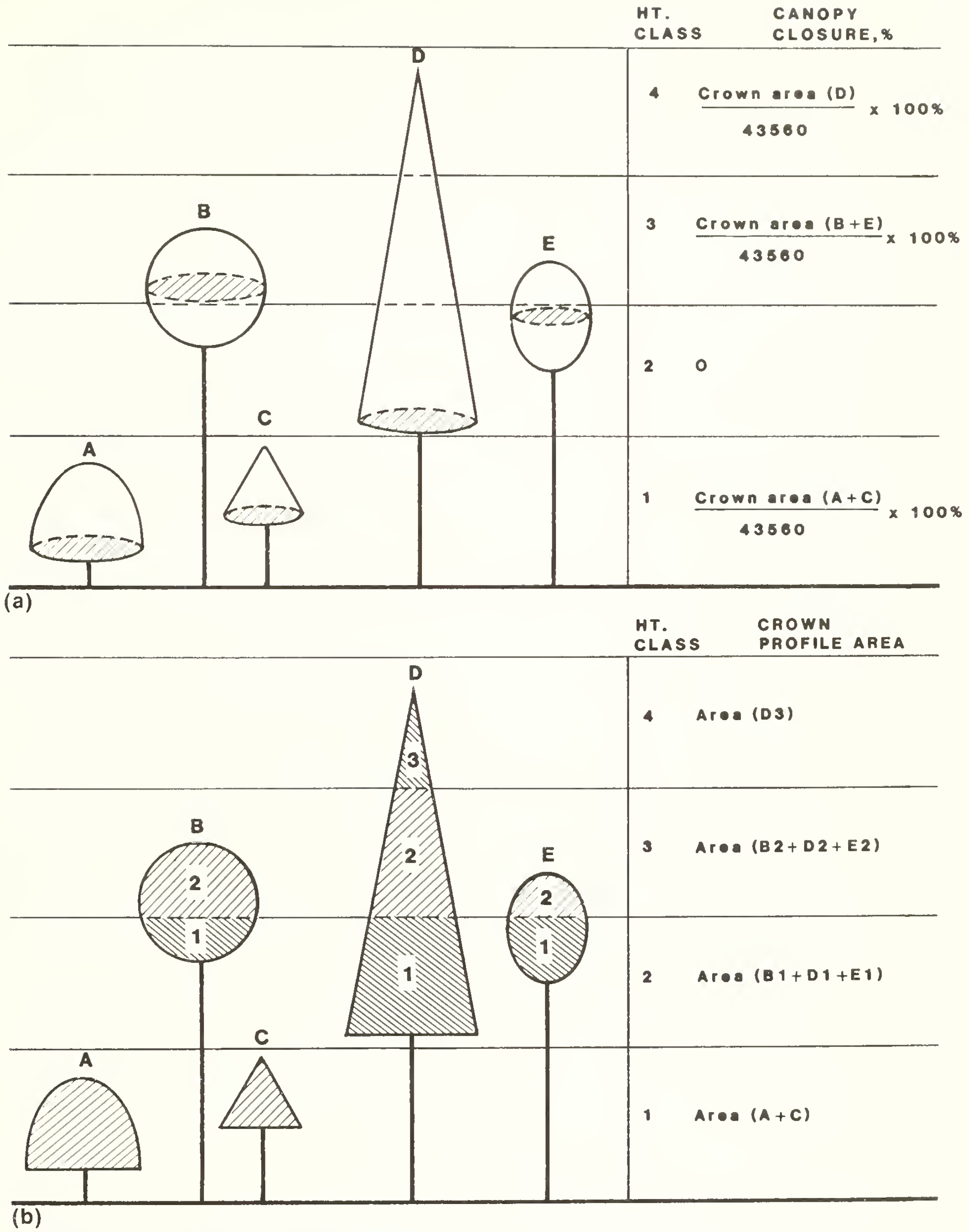


Figure 3.—Canopy structure computations in the CANOPY option of COVER: (a) canopy closure by 10-ft height class; (b) crown profile area by 10-ft height class.

Crown volume.—The volume in cubic feet per acre of tree crowns within height classes. Volume is determined using integration of standard volume formulas for conical, spherical, parabolic, elliptic, and neiloid crown forms.

Foliage biomass.—The biomass of foliage in pounds per acre in the stand, represented by the sum of foliage in individual crown sections within height classes.

Shrub Statistics Display

The second COVER display, shrub statistics by species (fig. 4) is produced when the SHRUBS keyword is present in the runstream. Predictions are made for each of 31 species or species groups listed in table 1. Nine species with the greatest predicted cover in the stand are always displayed: three each within low (less than 1.7 ft), medium (1.7—7 ft), and tall (7 ft and greater) height classes (Patterson and others 1985).

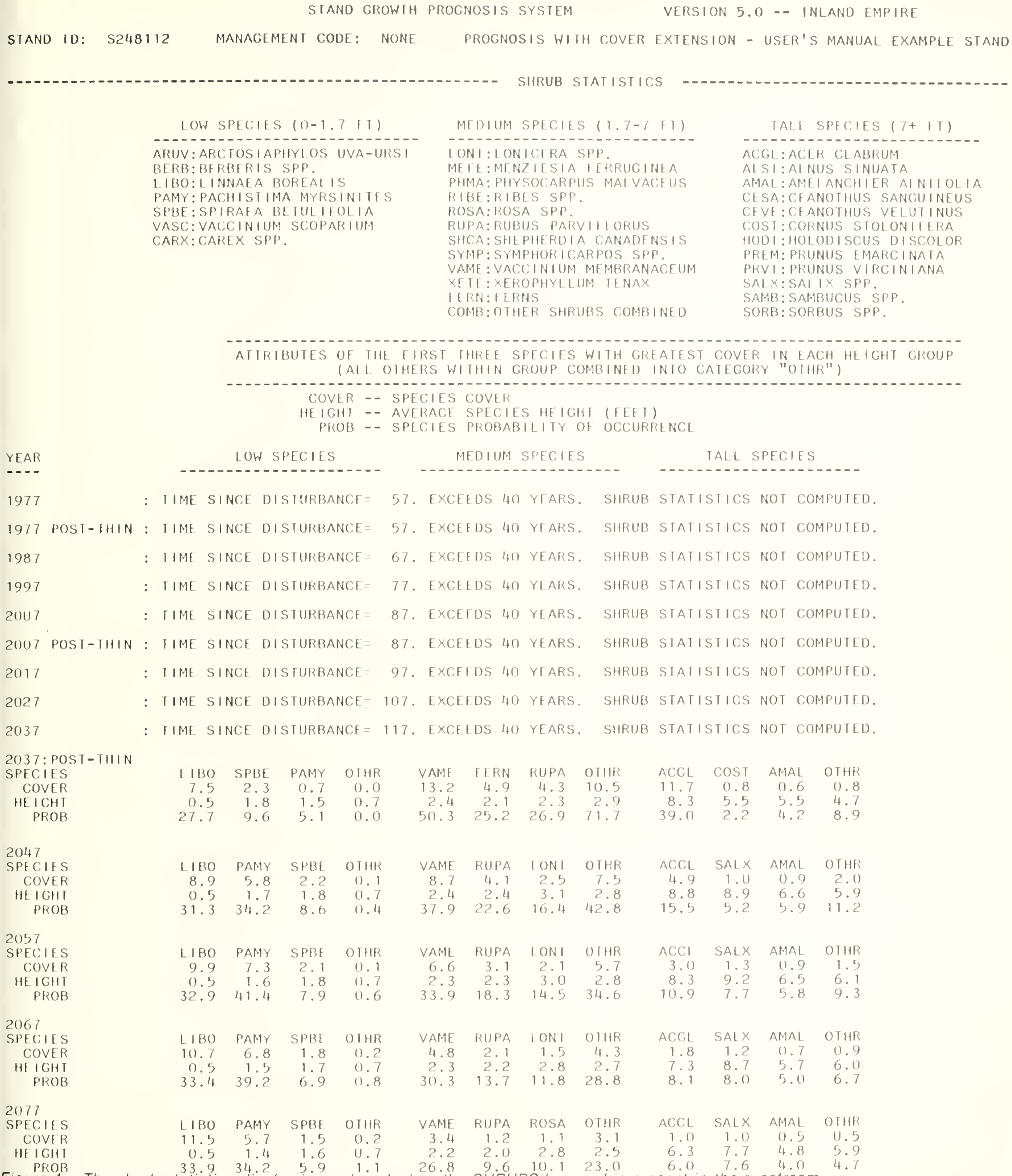
Cover.—The percentage of area covered by the canopy of an individual species projected vertically onto the ground. Species cover is weighted by probability of occurrence.

Height.—Average height of the species, in feet.

Probability of occurrence.—The proportion (expressed as a percentage) of 1/300-acre plots in the described stand that contain the indicated species.

The remaining species within each height class are combined into an "other" category. For these, cover is the sum of other species cover weighted by their probabilities, height is their average height weighted by species cover, and probability is the sum of their individual probabilities. In addition, the user may specify up to six species which will always be displayed, using the SHOWSHRB keyword card and supplemental data record.

Shrub values are computed only between 3 and 40 years following stand disturbance (the lower and upper limits of the range of data used to model shrub production). In the course of a projection, if a thinning causes canopy closure to fall below 50 percent, and if the thinned volume is at least 20 percent of the volume before thinning, then time since stand disturbance is reset to 3 years and shrub computations resume. In the example simulation, time since disturbance was incremented from initial stand age of 57 years until the overstory removal in year 2037. Neither the thinning in 1977 nor the one in 2007 opened the canopy enough to trigger shrub calculations in the program. The overwood cut in 2037 reduced crown closure from 98 percent to 14 percent, causing the shrub response calculations to begin.



```
                                    STAND GROWTH PROGNOSIS SYSTEM          VERSION 5.0 -- INLAND EMPIRE
STAND ID:  S248112      MANAGEMENT CODE:  NONE      PROGNOSIS WITH COVER EXTENSION - USER'S MANUAL EXAMPLE STAND

----------------------------------------------- SHRUB STATISTICS ---------------------------------------------

                     LOW SPECIES (0-1.7 FT)         MEDIUM SPECIES (1.7-7 FT)          TALL SPECIES (7+ FT)
                     -------------------------      --------------------------         -------------------------
                     ARUV:ARCTOSTAPHYLOS UVA-URSI   LONI:LONICERA SPP.                 ACGL:ACER GLABRUM
                     BERB:BERBERIS SPP.             MEFE:MENZIESIA FERRUGINEA          ALSI:ALNUS SINUATA
                     LIBO:LINNAEA BOREALIS          PHMA:PHYSOCARPUS MALVACEUS         AMAL:AMELANCHIER ALNIFOLIA
                     PAMY:PACHISTIMA MYRSINITES     RIBE:RIBES SPP.                    CESA:CEANOTHUS SANGUINEUS
                     SPBE:SPIRAEA BETULIFOLIA       ROSA:ROSA SPP.                     CEVE:CEANOTHUS VELUTINUS
                     VASC:VACCINIUM SCOPARIUM       RUPA:RUBUS PARVIFLORUS             COST:CORNUS STOLONIFERA
                     CARX:CAREX SPP.                SHCA:SHEPHERDIA CANADENSIS         HODI:HOLODISCUS DISCOLOR
                                                    SYMP:SYMPHORICARPOS SPP.           PREM:PRUNUS EMARGINATA
                                                    VAME:VACCINIUM MEMBRANACEUM        PRVI:PRUNUS VIRGINIANA
                                                    XETE:XEROPHYLLUM TENAX             SALX:SALIX SPP.
                                                    FERN:FERNS                         SAMB:SAMBUCUS SPP.
                                                    COMB:OTHER SHRUBS COMBINED         SORB:SORBUS SPP.

                              -----------------------------------------------------------------------------
                              ATTRIBUTES OF THE FIRST THREE SPECIES WITH GREATEST COVER IN EACH HEIGHT GROUP
                                         (ALL OTHERS WITHIN GROUP COMBINED INTO CATEGORY "OTHR")
                              -----------------------------------------------------------------------------
                                         COVER -- SPECIES COVER
                                        HEIGHT -- AVERAGE SPECIES HEIGHT (FEET)
                                          PROB -- SPECIES PROBABILITY OF OCCURRENCE

YEAR                           LOW SPECIES                MEDIUM SPECIES               TALL SPECIES
----                      ---------------------      ---------------------       ---------------------

1977            : TIME SINCE DISTURBANCE=  57. EXCEEDS 40 YEARS.  SHRUB STATISTICS NOT COMPUTED.

1977 POST-THIN  : TIME SINCE DISTURBANCE=  57. EXCEEDS 40 YEARS.  SHRUB STATISTICS NOT COMPUTED.

1987            : TIME SINCE DISTURBANCE=  67. EXCEEDS 40 YEARS.  SHRUB STATISTICS NOT COMPUTED.

1997            : TIME SINCE DISTURBANCE=  77. EXCEEDS 40 YEARS.  SHRUB STATISTICS NOT COMPUTED.

2007            : TIME SINCE DISTURBANCE=  87. EXCEEDS 40 YEARS.  SHRUB STATISTICS NOT COMPUTED.

2007 POST-THIN  : TIME SINCE DISTURBANCE=  87. EXCEEDS 40 YEARS.  SHRUB STATISTICS NOT COMPUTED.

2017            : TIME SINCE DISTURBANCE=  97. EXCEEDS 40 YEARS.  SHRUB STATISTICS NOT COMPUTED.

2027            : TIME SINCE DISTURBANCE= 107. EXCEEDS 40 YEARS.  SHRUB STATISTICS NOT COMPUTED.

2037            : TIME SINCE DISTURBANCE= 117. EXCEEDS 40 YEARS.  SHRUB STATISTICS NOT COMPUTED.

2037:POST-THIN
SPECIES                   LIBO  SPBE  PAMY  OTHR      VAME  FERN  RUPA  OTHR      ACGL  COST  AMAL  OTHR
  COVER                    7.5   2.3   0.7   0.0      13.2   4.9   4.3  10.5      11.7   0.8   0.6   0.8
 HEIGHT                    0.5   1.8   1.5   0.7       2.4   2.1   2.3   2.9       8.3   5.5   5.5   4.7
   PROB                   27.7   9.6   5.1   0.0      50.3  25.2  26.9  71.7      39.0   2.2   4.2   8.9

2047
SPECIES                   LIBO  PAMY  SPBE  OTHR      VAME  RUPA  LONI  OTHR      ACGL  SALX  AMAL  OTHR
  COVER                    8.9   5.8   2.2   0.1       8.7   4.1   2.5   7.5       4.9   1.0   0.9   2.0
 HEIGHT                    0.5   1.7   1.8   0.7       2.4   2.4   3.1   2.8       8.8   8.9   6.6   5.9
   PROB                   31.3  34.2   8.6   0.4      37.9  22.6  16.4  42.8      15.5   5.2   5.9  11.2

2057
SPECIES                   LIBO  PAMY  SPBE  OTHR      VAME  RUPA  LONI  OTHR      ACGL  SALX  AMAL  OTHR
  COVER                    9.9   7.3   2.1   0.1       6.6   3.1   2.1   5.7       3.0   1.3   0.9   1.5
 HEIGHT                    0.5   1.6   1.8   0.7       2.3   2.3   3.0   2.8       8.3   9.2   6.5   6.1
   PROB                   32.9  41.4   7.9   0.6      33.9  18.3  14.5  34.6      10.9   7.7   5.8   9.3

2067
SPECIES                   LIBO  PAMY  SPBE  OTHR      VAME  RUPA  LONI  OTHR      ACGL  SALX  AMAL  OTHR
  COVER                   10.7   6.8   1.8   0.2       4.8   2.1   1.5   4.3       1.8   1.2   0.7   0.9
 HEIGHT                    0.5   1.5   1.7   0.7       2.3   2.2   2.8   2.7       7.3   8.7   5.7   6.0
   PROB                   33.4  39.2   6.9   0.8      30.3  13.7  11.8  28.8       8.1   8.0   5.0   6.7

2077
SPECIES                   LIBO  PAMY  SPBE  OTHR      VAME  RUPA  ROSA  OTHR      ACGL  SALX  AMAL  OTHR
  COVER                   11.5   5.7   1.5   0.2       3.4   1.2   1.1   3.1       1.0   1.0   0.5   0.5
 HEIGHT                    0.5   1.4   1.6   0.7       2.2   2.0   2.8   2.5       6.3   7.7   4.8   5.9
   PROB                   33.9  34.2   5.9   1.1      26.8   9.6  10.1  23.0       6.0   7.6   4.0   4.7
```

Figure 4.—The shrub statistics display is produced when the SHRUBS keyword is present in the runstream.

Table 1.—Understory species for which predictions are currently made in the SHRUBS portion of the COVER program, height class, and source of information

Code	Scientific name	Common name	Height class[1]	Source[2]
ACGL	*Acer glabrum*	Rocky Mountain maple	T	a, b
ALSI	*Alnus sinuata*	Sitka alder	T	a
AMAL	*Amelanchier alnifolia*	Serviceberry	T	a, b
ARUV	*Arctostaphylos uva-ursi*	Kinnikinnick	L	a
BERB	*Berberis* spp.	Oregon grape	L	a
CARX	*Carex* spp.	Sedge	L	a
CESA	*Ceanothus sanguineus*	Redstem ceanothus	T	a, b
CEVE	*Ceanothus velutinus*	Shinyleaf ceanothus	T	a, b
COST	*Cornus stolonifera*	Red-osier dogwood	T	a
FERN	*Athyrium filix-femina* *Pteridium aquilinum*	Fern	M	a
HODI	*Holodiscus discolor*	Ocean-spray	T	a, b
LIBO	*Linnaea borealis*	Twinflower	L	a
LONI	*Lonicera* spp.	Honeysuckle	M	a, b
MEFE	*Menziesia ferruginea*	Menziesia	M	a
PAMY	*Pachistima myrsinites*	Pachistima	L	a, b
PHMA	*Physocarpus malvaceus*	Ninebark	M	a, b
PREM	*Prunus emarginata*	Bittercherry	T	a, b
PRVI	*Prunus virginiana*	Common chokecherry	T	a
RIBE	*Ribes* spp.	Currant	M	a, b
ROSA	*Rosa* spp.	Rose	M	a, b
RUPA	*Rubus parviflorus*	Thimbleberry	M	a, b
SALX	*Salix* spp.	Willow	T	a, b
SAMB	*Sambucus* spp.	Elderberry	T	a
SHCA	*Shepherdia canadensis*	Russett buffaloberry	M	a
SORB	*Sorbus* spp.	Mountain-ash	T	a
SPBE	*Spiraea betulifolia*	Shinyleaf spiraea	L	a, b
SYMP	*Symphoricarpos* spp.	Snowberry	M	a, b
VAME	*Vaccinium membranaceum* *Vaccinium globulare*	Big huckleberry Globe huckleberry	M	a, b
VASC	*Vaccinium scoparium*	Grouse whortleberry	L	a
XETE	*Xerophyllum tenax*	Common beargrass	M	a
COMB		Other shrubs combined	M	a

Artemisia tridentata
Clematis columbiana
Cornus nuttallii
Crataegus douglasii
Juniperus spp.
Ledum glandulosum
Lonicera caerulea
Lonicera involucrata
Oplopanax horridum
Philadelphus lewisii
Prunus pensylvanica
Purshia tridentata
Rhamnus purshiana
Rhododendron albiflorum
Rhus trilobata
Rubus leucodermis
Rubus ursinus
Spiraea pyramidata
Taxus brevifolia
Vaccinium caespitosum

---

[1] T = tall, M = medium, L = low (from Patterson and others 1985).

[2] a: Probability of occurrence from Scharosch (1984).
Height and percent cover from Laursen (1984).
b: Twig production and dormant season biomass (ABGR/CLUN, THPL/CLUN, TSHE/CLUN habitat types only) from Irwin and Peek (1979).

Canopy and Shrubs Summary Display

The third display is the Canopy and Shrubs Summary display (fig. 5).

Understory attributes:

Time since disturbance.—Time in years since the stand has been entered for harvest or site preparation. At the start of a projection, this value is set equal either to stand age or to the value entered on the SHRUBS keyword record, and is incremented by the length of each cycle. A thinning which reduces canopy closure below 50 percent and accounts for at least 20 percent of the prethinning volume causes time since disturbance to be reset to 3 years. See the previous section for more explanation.

Probability of shrub cover being greater than zero.—The proportion (expressed as a percentage) of 1/300-acre plots in the described stand that contain any shrub cover.

Shrub cover.—Sum of individual percentage cover, weighted by probability, for all species in low (0—1.7 ft), medium (1.7—7 ft), and tall (over 7 ft) height classes, and total shrub cover.

Average shrub height.—Average height in feet of all species, weighted by predicted species cover.

Dormant shrub biomass.—Total dormant season aboveground shrub biomass in pounds per acre.

Twig production.—Current year's number of twigs per square foot.
Shrub biomass and twig production are only computed for ABGR/CLUN, THPL/CLUN, and TSHE/CLUN habitat types (codes 520, 530, and 570).

Stand successional stage code.—A vegetation life form classification described by Peterson (1982), which provides a basis for relating wildlife use to the shrub and conifer structure of the stand.

Overstory attributes:

Stand age.—Overstory age in years, entered on the STDINFO card and incremented by the length of each projection cycle. The value of stand age will change during the projection if RESETAGE, a regeneration establishment model keyword (Ferguson and Crookston 1984), is used.

Top height.—Current average height in feet of the largest 40 trees per acre by d.b.h.

Canopy closure.—Total percentage canopy closure.

Crown foliage biomass.—Total foliage biomass in pounds per acre.

Sum of stem diameters.—The sum of stem diameters at breast height for all trees in the stand, in feet. This quantity may be used to compute stem area available for hiding cover by multiplying by height value of interest (for example, average shoulder height of an elk).

Number of stems.—Total number of trees per acre.

Shrub-small conifer competition:

If the SHRUBS option is in effect, a display similar in format to the Canopy Cover table is produced. It expands the resolution of the first 20 ft of the stand, and displays both shrub cover and number of trees cumulatively by height.

Shrub cover.—Total cover of shrubs whose predicted heights are greater than the current height.

Number of trees.—Total number of trees per acre whose heights are greater than the current height.

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                        STAND GROWTH PROGNOSIS SYSTEM          VERSION 5.0 -- INLAND EMPIRE

STAND ID:  S248112     MANAGEMENT CODE:   NONE      PROGNOSIS WITH COVER EXTENSION - USER'S MANUAL EXAMPLE STAND

----------------------------------------------  CANOPY AND SHRUBS SUMMARY  ----------------------------------------------

                                    -------- DEFINITIONS OF SUCCESSIONAL STAGE CODES USED IN OUTPUT --------
                                    1: RECENT DISTURBANCE                    6: TALL SHRUB WITH MOSTLY CONIFERS
                                    2: LOW SHRUB                             7: SAPLING TIMBER
                                    3: MEDIUM SHRUB                          8: POLE TIMBER
                                    4: TALL SHRUB WITH NO CONIFERS           9: MATURE TIMBER
                                    5: TALL SHRUB WITH FEW CONIFERS         10: OLD-GROWTH TIMBER

                  ------------------- UNDERSTORY ATTRIBUTES -------------------         ------------ OVERSTORY ATTRIBUTES ------------
          TIME      PROB.    -----SHRUB COVER----  AVG.     DORMANT                                                           SUM OF
          SINCE     (SHRUB                         SHRUB    SHRUB     TWIGS   SUCC.   STAND  TOP      CANOPY    FOLIAGE    STEM    NUMBER
          DISTURB.  COV>0)   LOW  MED  TALL TOTAL  HEIGHT   BIOMASS   (NO./   STAGE   AGE    HEIGHT   CLOSURE   BIOMASS    DIAMS.   OF
DATE      (YEARS)   (%)      (%)  (%)  (%)  (%)    (FEET)   (LB/AC)   SQFT)   CODE    (YRS)  (FEET)   (%)       (LB/AC)    (FEET)  STEMS
---------------------------------------------------------------------------------------------------------------------------------------
1977         57                                                                        57     63       84        6742       185     590
POST-THIN    57                                                                        57     64       69        6066       147     264
1987         67                                                                        67     68       65        8493       169     244
1997         77                                                                        77     76       76       10418       186     224
2007         87                                                                        87     78       85       12171       195     204
POST-THIN    87                                                                        87     77       78       11623       154     157
2017         97                                                                        97     84       87       13312       164     147
2027        107                                                                       107     92       91       13937       170     136
2037        117                                                                       117     98       94       14381       173     126
POST-THIN     3      78       11   33   14   57     3.5      388       2.3     6       117    100       14        2933        50      35
2047         10      78       17   23    9   48     3.0      876       3.0     6       127     89       29        5788       120    2261
2057         20      75       19   18    7   44     2.7      607       0.3     6       137     95       55        7551       207    3090
2067         30      69       19   13    5   37     2.3      272       0.0     7       147    101       85        8950       265    2421
2077         40      58       19    9    3   31     1.8      101       0.0     7       157    107      111       10728       325    1921
---------------------------------------------------------------------------------------------------------------------------------------


----------------------------------------------  SHRUB-SMALL CONIFER COMPETITION  ----------------------------------------------

                                SHRUB COVER -- TOTAL COVER OF SHRUBS GREATER THAN HEIGHT
                                TREES/ACRE  -- TOTAL NUMBER OF TREES PER ACRE GREATER THAN HEIGHT

---------------------------------------------------------------------------------------------------------------------------------------
                                                         HEIGHT (FEET)
YEAR                           0.0    0.5    1.0    2.0    3.0    4.0    5.0    7.5   10.0   15.0   20.0
---------------------------------------------------------------------------------------------------------------------------------------
POST-THIN : SHRUB COVER         57     50     50     46     17     14     13     12      0      0      0
            TREES/ACRE          35     35     35     35     35     35     35     35     35     35     35

2047        SHRUB COVER         48     39     39     31     14      9      9      6      0      0      0
            TREES/ACRE        2261   2261   1717    838    531    297    209    100     69     32     32

2057        SHRUB COVER         44     34     34     23     11      7      7      4      0      0      0
            TREES/ACRE        3090   3090   2433   1936   1486   1191    948    381    217     74     32

2067        SHRUB COVER         37     26     26     17      6      5      4      1      0      0      0
            TREES/ACRE        2421   2421   2421   2282   1973   1647   1411    984    726    286    123

2077        SHRUB COVER         31     19     19     10      4      3      2      1      0      0      0
            TREES/ACRE        1921   1921   1921   1921   1890   1803   1663   1304    923    551    330
---------------------------------------------------------------------------------------------------------------------------------------
```

Figure 5.—Canopy and shrubs summary display.

PROGRAM ORGANIZATION

Each projection cycle in the Prognosis Model starts with simulated thinnings if thinning activities have been scheduled for that cycle. If either the CANOPY or SHRUBS option has been selected, crown and shrub statistics are computed and displayed following the thinning. Next, diameter and height growth, change in crown ratio, and mortality rate are computed for each tree record in the inventory by the main program. The tree attributes are updated at the end of the cycle and then crown and shrub statistics are computed once again. Thus, in thinning cycles, COVER values are computed and displayed twice. In projection cycles with no thinning, there is only one call to the COVER extension at the end of the cycle.

Crown cover and shrub predictions are displayed following a thinning to show the immediate effects of treatment on cover development. Predictions and display for crowns and for shrubs are handled somewhat differently in the postthin sequence. In the CANOPY subprogram, the crown models use prethin levels of stand density statistics (trees per acre, basal area, and relative diameter) to predict crown dimensions on remaining trees. This is done because no immediate response in crown dimension or foliage on residual trees to a change in stand density would be expected. In the SHRUBS subprogram, predictions are made using postthin stand density statistics to reflect the more rapid response of understory plants that one would expect following an opening up of the canopy.

The COVER extension may be used in conjunction with ESTAB, a Prognosis Model extension that simulates regeneration and subsequent development of a regenerated stand (Ferguson and Crookston 1984). Inside the combined COVER, ESTAB, and Prognosis Models, shrub values are computed prior to the establishment of new trees. Although presently ESTAB does not include effects of shrub development on the establishment of new trees, the computation sequence has been set up in anticipation of feedback between the shrubs and regeneration systems. For now, the shrub-small conifer display in the Summary table may help the user examine effects of shrub competition on newly established trees.

Shrub statistics (probability of occurrence, height, cover, biomass, and twig production) are not computed if time since disturbance exceeds 40 years. If the COVER extension is used in conjunction with the regeneration establishment model, and stand age is reset to a value less than 40 years using the RESETAGE keyword, shrub calculations will resume. Also, as discussed previously, shrub statistics will resume beginning with the postthin predictions for a cycle in which a heavy thinning takes place. Canopy cover statistics are displayed regardless of the value for time since disturbance.

KEYWORD DESCRIPTIONS

The keyword system used in the COVER extension is similar to that used for the Prognosis Model. Presently, 13 keywords are used to invoke the CANOPY or SHRUBS options, supply needed information to the extension, or modify its output. The position of these cards in the Prognosis Model deck is unimportant except that they should be in a group beginning with the COVER keyword and ending with the END keyword. Like all other keywords, they must precede the PROCESS card. Formatting of keyword records follows the scheme used for all other Prognosis Model keywords. Columns 1 to 10 are reserved for the keyword itself, followed by seven parameter fields of 10 columns each. Numeric data should be right-justified within the parameter field, or include a decimal point. Three of the keyword records in the SHRUBS option are followed by supplemental data records. The END record signifies the end of keywords for the extension and returns control to the main program. The appendix summarizes keyword records available in the COVER option.

Calling the Extension

COVER Keyword

The COVER keyword record signifies the beginning of keywords for the extension. It has two parameter fields.

COVER field 1: Cycle number in which COVER calculations begin; default = beginning of projection. COVER calculations will be performed in all cycles subsequent to the specified one.

field 2: Dataset reference number for COVER output; default = 18.

Overstory Options

CANOPY Keyword

The CANOPY keyword invokes the crown cover options of the extension, which compute crown width, shape, and foliage biomass for each tree record, and tree cover summary statistics for the stand. It has no parameter fields associated with it.

Understory Options

SHRUBS Keyword

The SHRUBS keyword tells the program to compute shrub statistics. It has four parameter fields.

SHRUBS field 1: Time in years since stand disturbance; default = stand age. If stand age is not supplied, default = 3 years.

field 2: Habitat type code selected for processing shrub options. Table 2 lists habitat types for which shrub predictions are made; default = stand habitat type code.

field 3: Physiographic type code. 1 = bottom, 2 = lower slope, 3 = midslope, 4 = upper slope, 5 = ridge; default = 2.

field 4: Disturbance type code. 1 = none, 2 = mechanical, 3 = burn, 4 = road; default = 1.

As indicated, each of the SHRUBS keyword parameters has a default value in the event that no value is supplied by the user. The value entered for time since disturbance should be the number of years since the stand was entered for harvest or site preparation. Time since disturbance will be set to stand age entered on the STDINFO keyword record if the user fails to supply a value on the SHRUBS keyword, and will be incremented by the length of each projection cycle. Although stand age is not used by the Prognosis Model to calculate tree growth, time since disturbance is a significant predictor of shrub development. As noted previously, shrub calculations are performed only if the current value of time since disturbance is between 3 and 40 years. Three situations may occur to reset time since disturbance. First, if a value less than 3 years is entered (or if the age fields on both the SHRUBS and STDINFO keywords are left blank), initial time since disturbance will be set to 3 years. Second, if a scheduled thinning causes canopy closure to fall below 50 percent, and if the volume removed is 20 percent or more of the volume before thinning, then disturbance time is reset to 3 years. Finally, if the Regeneration Establishment Model is being used, and stand age is reset to a value less than 40 years using

Table 2.—Valid habitat type codes for the SHRUBS option (from Pfister and others 1977; Steele and others 1981)

Abbreviations	Codes	Habitat types and phases
		Pseudotsuga menziesii series
PSME/AGSP	210	*Pseudotsuga menziesii/Agropyron spicatum*
PSME/FEID	220	*Pseudotsuga menziesii/Festuca idahoensis*
PSME/PHMA	260	*Pseudotsuga menziesii/Physocarpus malvaceus*
PSME/SYAL	310	*Pseudotsuga menziesii/Symphoricarpos albus*
PSME/CARU	320	*Pseudotsuga menziesii/Calamagrostis rubescens*
PSME/CAGE	330	*Pseudotsuga menziesii/Carex geyeri*
PSME/SPBE	340	*Pseudotsuga menziesii/Spiraea betulifolia*
PSME/SYOR	380	*Pseudotsuga menziesii/Symphoricarpos oreophilus*
PSME/ACGL	390	*Pseudotsuga menziesii/Acer glabrum*
PSME/BERE	395	*Pseudotsuga menziesii/Berberis repens*
		Abies grandis series
ABGR/SPBE	505	*Abies grandis/Spiraea betulifolia*
ABGR/XETE	510	*Abies grandis/Xerophyllum tenax*
ABGR/COOC	511	*Abies grandis/Coptis occidentalis*
ABGR/VAGL	515	*Abies grandis/Vaccinium globulare*
ABGR/CLUN	520	*Abies grandis/Clintonia uniflora*
ABGR/ACGL	525	*Abies grandis/Acer glabrum*
ABGR/LIBO	590	*Abies grandis/Linnaea borealis*
		Thuja plicata series
THPL/CLUN	530	*Thuja plicata/Clintonia uniflora*
THPL/ATFI	540	*Thuja plicata/Athyrium filix-femina*
THPL/OPHO	550	*Thuja plicata/Oplopanax horridum*
		Tsuga heterophylla series
TSHE/CLUN	570	*Tsuga heterophylla/Clintonia uniflora*
		Abies lasiocarpa series
ABLA/CLUN	620	*Abies lasiocarpa/Clintonia uniflora*
ABLA/STAM	635	*Abies lasiocarpa/Streptopus amplexifolius*
ABLA/ACGL	645	*Abies lasiocarpa/Acer glabrum*
ABLA/CACA	650	*Abies lasiocarpa/Calamagrostis canadensis*
ABLA/MEFE	670	*Abies lasiocarpa/Menziesia ferruginea*
ABLA/XETE	690	*Abies lasiocarpa/Xerophyllum tenax*
ABLA/SPBE	705	*Abies lasiocarpa/Spiraea betulifolia*
TSME/XETE	710	*Tsuga mertensiana/Xerophyllum tenax*
ABLA/VAGL	720	*Abies lasiocarpa/Vaccinium globulare*
ABLA/VAGL	721	*Abies lasiocarpa/Vaccinium globulare, Vaccinium scoparium* phase
ABLA/VASC	730	*Abies lasiocarpa/Vaccinium scoparium*
ABLA/CAGE	790	*Abies lasiocarpa/Carex geyeri*
ABLA/LUHI	830	*Abies lasiocarpa/Luzula hitchcockii*

the RESETAGE keyword, time since disturbance will also be reset to the same value.

Shrub statistics will be computed only if a valid habitat type code is encountered. Even if a code other than those listed in table 2 has been entered for the stand on the STDINFO record, the user may supply a separate habitat code that affects only the SHRUBS option. Thus shrub predictions may be made (at the user's discretion) by substituting a similar valid habitat type code. Allowing predictions to be made for similar habitat types assumes that, even though habitat type classification is based on unique potential climax vegetation, seral community development may not be unique and similar habitat types may respond with fairly similar shrub communities in the first 40 years following disturbance. If a substitute habitat type code is used, the program writes a cautionary message to that effect.

Shrub Calibration Options

If shrub information has been recorded in the inventory, it may be used to adjust the embedded models to reflect unique variations in site and environment. Shrub height, cover, and occurrence models may be calibrated using either of two types of data collected according to Region 1 Stand Examination Procedures (USDA 1983). The two methods are to measure the height and average cover of up to three distinct shrub layers in the stand, or alternatively to measure the height and cover of individual species. When real shrub measurements are provided to the model, the information is used to scale predictions to match observed values. The scaling factors are computed only once, at the start of the first cycle, and are applied to the predictions for all cycles until a simulated thinning occurs. Because the course of shrub development may be expected to be altered following a thinning, the original information input for calibration may no longer be appropriate. Thus, once a thinning occurs, all calibration ceases and shrub predictions are no longer multiplied by the scaling factors.

SHRBLAYR Keyword

This keyword is one of two possible methods for providing field data with which to calibrate the shrub predictions. The SHRBLAYR keyword record contains six fields of 10 columns each for recording average height and percentage of ground cover value for each distinct shrub layer (up to three layers) in the understory. There is no inherent height or percentage of cover ranking of the layers; they may be entered in any order. The information is coded according to the following format:

SHRBLAYR field 1: average height of shrub layer 1, in feet
field 2: percentage of cover of shrub layer 1
field 3: average height of shrub layer 2, in feet
field 4: percentage of cover of shrub layer 2
field 5: average height of shrub layer 3, in feet
field 6: percentage of cover of shrub layer 3

The SHRBLAYR method of calibration sorts the shrub species by uncalibrated predicted height at the beginning of the projection. Progressing down through the species list from predicted tallest to shortest, the individual uncalibrated shrub cover predictions, weighted by probability of occurrence, are summed. When the sum of cover accounts for the same proportion as entered for the tallest shrub layer on the SHRBLAYR card, the summing ceases, and those species are grouped into a class. The process is repeated for each input layer. Once the classes are delineated, average predicted height and total cover for each layer are computed and compared to the entered values for the layers. Scaling factors are computed that adjust the predicted values to match the input calibration values. The scaling factors are applied individually to the cover and height predictions of each species within delineated classes.

The calibration values entered on the SHRBLAYR card and the computed scaling factors are displayed in the Shrub Model Calibration Statistics display (fig. 6). This display is printed immediately preceding the Shrub Statistics display if calibration is specified.

```
                                    STAND GROWTH PROGNOSIS SYSTEM         VERSION 5.0 -- INLAND EMPIRE
STAND ID:  S248112      MANAGEMENT CODE:  NONE      PROGNOSIS WITH COVER EXTENSION - SHRUB LAYER CALIBRATION


--------------------------------------------- SHRUB MODEL CALIBRATION STATISTICS ---------------------


CALIBRATION BY SHRUB LAYER (SHRBLAYR KEYWORD CARD):
         AVERAGE HEIGHT (FEET)                             AVERAGE PERCENT COVER
    -----------------------------------         -----------------------------------
    SHRUB  OBSERVED   PREDICTED   SCALING       SHRUB  OBSERVED   PREDICTED   SCALING
    LAYER  VALUES     VALUES      FACTORS       LAYER  VALUES     VALUES      FACTORS
    -----  --------   ---------   -------       -----  --------   ---------   -------

      1       6.0          5.4     1.10           1      10.0          8.2     1.21
      2       3.0          2.3     1.31           2      20.0         17.1     1.17
      3       1.0          0.9     1.11           3      20.0         17.2     1.16

                                HEIGHT         % COVER
     SHRUB      ASSIGNED        SCALING        SCALING
    SPECIES      LAYER          FACTOR         FACTOR
    -------     --------       ---------      ---------

      ARUV          3             1.11           1.16
      BERB          3             1.11           1.16
      LIBO          3             1.11           1.16
      PAMY          3             1.11           1.16
      SPBE          2             1.31           1.17
      VASC          3             1.11           1.16
      CARX          3             1.11           1.16
      LONI          2             1.31           1.17
      MEFE          1             1.10           1.21
      PHMA          1             1.10           1.21
      RIBE          1             1.10           1.21
      ROSA          2             1.31           1.17
      RUPA          2             1.31           1.17
      SHCA          1             1.10           1.21
      SYMP          2             1.31           1.17
      VAME          2             1.31           1.17
      XETE          3             1.11           1.16
      EERN          2             1.31           1.17
      COMB          1             1.10           1.21
      ACGL          1             1.10           1.21
      ALSI          1             1.10           1.21
      AMAL          1             1.10           1.21
      CESA          1             1.10           1.21
      CEVE          1             1.10           1.21
      COST          1             1.10           1.21
      HODI          1             1.10           1.21
      PREM          1             1.10           1.21
      PRVI          1             1.10           1.21
      SALX          1             1.10           1.21
      SAMB          1             1.10           1.21
      SORB          1             1.10           1.21
```

Figure 6.—Shrub model calibration by shrub layer, performed when the following keyword records are specified:

```
COVER
SHRUBS            20.0       570.0        3.0
SHRBLAYR           1.0        20.0        3.0        20.0        6.0        10.0
END
```

SHRUBPC and SHRUBHT Keywords

The SHRUBPC and SHRUBHT keywords are used to supply calibration information in instances where cover and/or average height measurements have been gathered for some or all of the individual species.

The format for the two keywords is identical, each requiring up to five cards for its input. The leading card has just the keyword entered on it. Following are up to four supplemental data records containing eight fields of 10 columns each. The first four columns of each field are used to identify the shrub species, using the abbreviations given in table 1. The remaining six columns are used to enter the corresponding percentage of cover for the SHRUBPC keyword or height in feet for the SHRUBHT keyword. For example, to enter a 50 percent cover statistic for Rocky Mountain maple, the field would appear as:

`ACGL__50.0`

If no data were collected for a given species, there should be no entry for that species. If the species was included in the field survey but did not occur in the stand, it would be entered in the following manner:

`ACGL___0.0`

Shrub species may be in any order on the supplemental records. Enter "−999" in the shrub code field following the last shrub entry to signify the end of the SHRUBPC (or SHRUBHT) data.

```
                                   STAND GROWTH PROGNOSIS SYSTEM          VERSION 5.0 -- INLAND EMPIRE

STAND ID:  S248112      MANAGEMENT CODE:  NONE      PROGNOSIS WITH COVER EXTENSION - SHROB SPECIES CALIBRATION


-------------------------------------------- SHROB MODEL CALIBRATION STATISTICS -------------------------


CALIBRATION BY INDIVIDUAL SPECIES (SHRUBHT AND/OR SHROBPC KEYWORD CARDS):

                          SHRUB HEIGHT (FEET)                            PERCENT COVER
                     -------------------------------         -------------------------------
      SHROB         OBSERVED      PREDICTED     SCALING      OBSERVED      PREDICTED     SCALING
     SPECIES          VALUE         VALUE        FACTOR        VALOE         VALOE        FACTOR
     -------       ----------    ---------     --------    ----------    ---------     --------
       ARUV           0.0           0.5          0.00          0.0           0.0          0.00
       BERB                         0.8          1.00                        0.0          1.00
       LIBO           0.5           0.5          1.00         10.0           9.9          1.01
       PAMY           2.0           1.6          1.24          6.0           7.9          0.76
       SPBE                         1.8          1.00                        2.1          1.00
       VASC           0.0           0.9          0.00          0.0           0.0          0.00
       CARX           0.0           0.5          0.00          0.0           0.0          0.00
       LONI                         3.0          1.00                        2.1          1.00
       MEFE           5.0           4.0          1.26          1.0           1.0          0.97
       PHMA                         3.7          1.00                        0.3          1.00
       RIBE                         3.2          1.00                        0.5          1.00
       ROSA                         2.9          1.00                        1.4          1.00
       RUPA                         2.3          1.00                        3.1          1.00
       SHCA                         3.9          1.00                        0.0          1.00
       SYMP                         1.7          1.00                        0.8          1.00
       VAME           2.0           2.3          0.86          5.0           6.2          0.80
       XETE           0.0           1.5          0.00          0.0           0.0          0.00
       FERN           2.0           2.1          0.96          5.0           1.6          3.06
       COMB                         4.1          1.00                        0.2          1.00
       ACGL          10.0           8.3          1.21          2.0           3.3          0.61
       ALSI                         3.7          1.00                        0.1          1.00
       AMAL                         6.5          1.00                        0.9          1.00
       CESA                         7.3          1.00                        0.2          1.00
       CEVE                         5.2          1.00                        0.2          1.00
       COST                         5.4          1.00                        0.4          1.00
       HODI                         6.1          1.00                        0.3          1.00
       PREM           0.0           5.4          0.00          0.0           0.0          0.00
       PRVI                         9.3          1.00                        0.2          1.00
       SALX                         9.2          1.00                        1.3          1.00
       SAMB                         4.7          1.00                        0.0          1.00
       SORB                         4.4          1.00                        0.1          1.00
```

Figure 7.—Shrub model calibration by species, performed when the following keyword records are specified:

```
COVER
SHRUBS              20.0      570.0         3 0
SHRUBHT
ACGL      10.0MEFE       5.0VAME       2.0PAMY       2.0LIBO       0.5PREM       0.0XETE       0.0FERN       2.0
ARUV       0.0VASC       0.0CARX       0.0-999
SHRUBPC
ACGL       2.0MEFE       1.0VAME       5.0PAMY       6.0LIBO      10.0PREM       0.0XETE       0.0FERN       5.0
ARUV       0.0VASC       0.0CARX       0.0-999
END
```

The SHRUBPC and SHRUBHT keywords do not both have to be present in a given projection, although it is desirable. If only one of the keywords is present, only that portion of the calibration will be performed. The SHRBLAYR keyword should not be included when using the SHRUBPC and/or SHRUBHT keywords.

The data supplied on the SHRUBPC and SHRUBHT keyword cards are used to adjust probability of occurrence, height, and cover predictions for individual shrub species. Scaling factors are computed for each species as the ratio of actual to predicted height and cover at the start of the projection. Any species recorded as absent is given a zero probability of occurrence. In each cycle, these scaling factors are applied to the appropriate species and prediction. Scaling factors are ignored after the first simulated thinning.

Height and cover calibration factors by species are output in the Shrub Model Calibration Statistics Display (fig. 7).

Additional Keywords

There are seven additional keywords in the COVER extension. The first, SHOWSHRB, is used to select up to six understory species for which output will always be displayed. These are in addition to the nine species that account for the most cover. It requires one supplemental data record containing shrub species codes (table 1) in six fields of 10 columns each. The four-character codes must be right-justified within the fields.

Card 1: SHOWSHRB

Card 2: Cols. 1—10: abbreviation for first species

•

•

•

Cols. 51—60: abbreviation for last species

Three keywords are used to turn off printing of the displays:

NOCOVOUT	Suppress output of Canopy Cover Statistics display; default = table printed.
NOSHBOUT	Suppress output of the Shrub Statistics display; default = table printed.
NOSUMOUT	Suppress output of the Canopy and Shrubs Summary display; default = table printed.

The final three keywords are used to request information about the program, print intermediate debug information, and to signify the end of the COVER options:

DATELIST	Print date of last revision of COVER model subprograms and common areas.
DEBUG	Request printout of the results of most calculations for all tree and shrub records (caution: voluminous output!). field 1: Cycle number in which debug output is to be printed; default = output printed in all cycles.
END	Signify the end of COVER keywords and return control to the main program.

The COVER keywords for the example stand are echoed in the Prognosis Model Input Summary table (fig. 8).

```
                             STAND GROWTH PROGNOSIS SYSTEM          VERSION 5.0 -- INLAND EMPIRE
--------------------------------------------------------------------------------------------------------

                                              OPTIONS SELECTED BY INPUT

--------------------------------------------------------------------------------------------------------
KEYWORD    PARAMETERS:
---------  ---------------------------------------------------------------------------------------------
STDIDENT
           STAND ID= S248112          PROGNOSIS WITH COVER EXTENSION - USER'S MANUAL EXAMPLE STAND

DESIGN     BASAL AREA FACTOR=  40.0; INVERSE OF FIXED PLOT AREA=  300.0; BREAK DBH=    5.0
           SEE "OPTIONS SELECTED BY DEFAULT" FOR REMAINING DESIGN CARD PARAMETERS.

STDINFO    FOREST CODE= 18; HABITAT TYPE=570; AGE=   57; ASPECT CODE=  8.; SLOPE CODE=  3.
           ELEVATION(100'S FEET)= 34.0; SITE INDEX=   0.

INVYEAR    INVENTORY YEAR= 1977

NUMCYCLE   NUMBER OF CYCLES= 10

THINPRSC   DATE/CYCLE= 1980; PROPORTION OF SELECTED TREES REMOVED= 0.999

SPECPREF   DATE/CYCLE= 2010; SPECIES=  2.; THINNING SELECTION PRIORITY=  999.

SPECPREF   DATE/CYCLE= 2010; SPECIES=  7.; THINNING SELECTION PRIORITY= 9999.

THINBTA    DATE/CYCLE= 2010; RESIDUAL=  157.00; PROPORTION OF SELECTED TREES REMOVED= 0.980
           DBH OF REMOVED TREES WILL RANGE FROM   0.0 TO 999.0 INCHES

SPECPREF   DATE/CYCLE= 2040; SPECIES=  3.; THINNING SELECTION PRIORITY= -999.

SPECPREF   DATE/CYCLE= 2040; SPECIES=  4.; THINNING SELECTION PRIORITY=  -99.

THINBTA    DATE/CYCLE= 2040; RESIDUAL=   35.00; PROPORTION OF SELECTED TREES REMOVED= 0.980
           DBH OF REMOVED TREES WILL RANGE FROM   0.0 TO 999.0 INCHES

ESTAB      REGENERATION ESTABLISHMENT OPTIONS:
           DATE OF DISTURBANCE= 2037

END        REGENERATION TALLY ONE SCHEDULED FOR 2046, AND TALLY TWO FOR 2056
           END OF ESTABLISHMENT KEYWORDS

COVER      COVER OPTIONS:
           CYCLE=     1
           DATA SET REFERENCE NUMBER =  18

CANOPY     CANOPY MODEL CALCULATIONS: TREE CROWN WIDTH, CROWN SHAPE, AND FOLIAGE BIOMASS

SHRUBS     SHRUB MODEL OPTIONS:
           TIME SINCE DISTURBANCE =  57.0 YEARS
           HABITAT TYPE = 570 SELECTED FOR PROCESSING SHRUBS OPTIONS
           PHYSIOGRAPHY TYPE =    3 (MIDSLOPE)

END        END COVER OPTIONS

TREEDATA   DATA SET REFERENCE NUMBER=  5

PROCESS    PROCESS THE STAND.
--------------------------------------------------------------------------------------------------------
```

Figure 8.—Prognosis Model input options table showing COVER keywords.

OVERVIEW OF THE COVER SUBMODELS

CANOPY Submodels

Crown Width and Stand Canopy Closure.—COVER predicts crown development for the 11 conifer species listed in table 3. Logarithmic regression equations are used to predict individual tree crown width from species, d.b.h., height, and crown length for trees 3.5 inches d.b.h. and larger. For trees less than 3.5 inches d.b.h., crown width is a function of species, height, crown length, and stand basal area (Moeur 1981). Coefficient values for the crown width models for large and small trees are shown in tables 4 and 5, respectively.

Individual tree crown area is computed as the area of a circle with diameter equal to predicted crown width. Stand canopy closure is computed from the sum of the tree crown areas,

$$\text{canopy closure} = \frac{\Sigma \text{ crown areas (ft}^2\text{/acre)}}{43{,}560 \text{ ft}^2\text{/acre}} \times 100 \text{ percent.}$$

Table 3.—Tree species recognized by COVER

Code	Common name	Scientific name
WP	Western white pine	*Pinus monticola*
L	Western larch	*Larix occidentalis*
DF	Douglas-fir	*Pseudotsuga menziesii*
GF	Grand fir	*Abies grandis*
WH	Western hemlock	*Tsuga heterophylla*
C	Western redcedar	*Thuja plicata*
LP	Lodgepole pine	*Pinus contorta*
S	Engelmann spruce	*Picea engelmannii*
AF	Subalpine fir	*Abies lasiocarpa*
PP	Ponderosa pine	*Pinus ponderosa*
Other	Whitebark pine	*Pinus albicaulis*

Table 4.—Coefficients for estimating crown width of trees 3.5 inches d.b.h. and larger (Moeur 1981): $\ln(\text{crown width}) = b_0 + b_1\ln(D) + b_2\ln(H) + b_3\ln(CL)$

	Variable coefficients[2]	
Species[1]	Intercept b_0	ln(H) b_2
WP	4.30800	−1.37264
L	2.31359	−.80919
DF	3.02271	−1.00486
GF	2.20611	−.76936
WH	1.32772	−.52554
C	2.79784	−.89666
LP	1.06804	−.55987
S	3.76535	−1.18257
AF	1.74558	−.73972
PP	1.62365	−.68098
Other	−.91984	−.07299

Variables	Variable coefficients
ln(D)	b_1 = 1.08137
ln(CL)	b_3 = .29786

[1] Species codes are given in table 3.

[2] Definition of variables:

D = diameter breast height (inches)
H = tree height (ft)
CL = crown length (ft).

Table 5.—Coefficients for estimating crown width of trees less than 3.5 inches (Moeur 1981):
$\ln(\text{crown width}) = b_1\ln(H) + b_2\ln(CL) + b_3\ln(BA)$

Species[1]	Variable coefficients[2] ln(H) b_1
WP	0.37031
L	.23846
DF	.32874
GF	.38503
WH	.25622
C	.46452
LP	.26342
S	.33089
AF	.33722
PP	.36380
Other	.07049

Variables	Variable coefficients
ln(CL)	$b_2 = 0.28283$
ln(BA)	$b_3 = .04032$

[1] Species codes are given in table 3.

[2] Definition of variables:
H = tree height (ft)
CL = crown length (ft)
BA = stand basal area (ft^2/acre).

In the following discussion, model behavior is displayed in the plots of simulation results from five stands whose site characteristics are listed in table 6. In each 100-year simulation, the stand was clearcut in period 1, the site was prepared by burning, and a new tree list predicted using the Regeneration Establishment Model (Ferguson and Crookston 1984). These "bare-ground" regeneration projections were used to compare responses of the crown relationships to changes in stand structure and density through time.

Table 6.—Site characteristics of the stands used to examine crown model behavior. In each simulation, the stand was clearcut, the site was prepared by burning, and regenerated using the Regeneration Establishment Model

Code	Stand	Location	Habitat type	Aspect	Slope	Elevation
					Percent	*Feet*
E	S248112	St. Joe	570 (TSHE/CLUN)	NW	30	3,400
W	Weippe	Clearwater	530 (THPL/CLUN)	NW	20	4,000
C	Cranberry	Clearwater	530 (THPL/CLUN)	S	10	3,000
G	Grouse	Clearwater	520 (ABGR/CLUN)	N	10	3,100
S	Silver	Clearwater	520 (ABGR/CLUN)	S	20	3,000

Canopy closure follows an increasing sigmoidal pattern over time on regenerated stands (fig. 9). Cover increases fairly rapidly between 0 and 20 years, as the first and second waves of regeneration produced by the establishment model enter the tree list. Then, even though numbers of trees start to decline beyond 20 years, canopy closure increases as individual tree crown width continues to expand. In the stands where canopy closure reaches 100 percent and greater, crown cover peaks and then declines beyond about 50 years in the projection (stands E, W, and G). Canopy closure is incomplete on the stands where establishment is poor (C and S). Here, crown cover levels off about 70 years after regeneration, rather than peaking and declining.

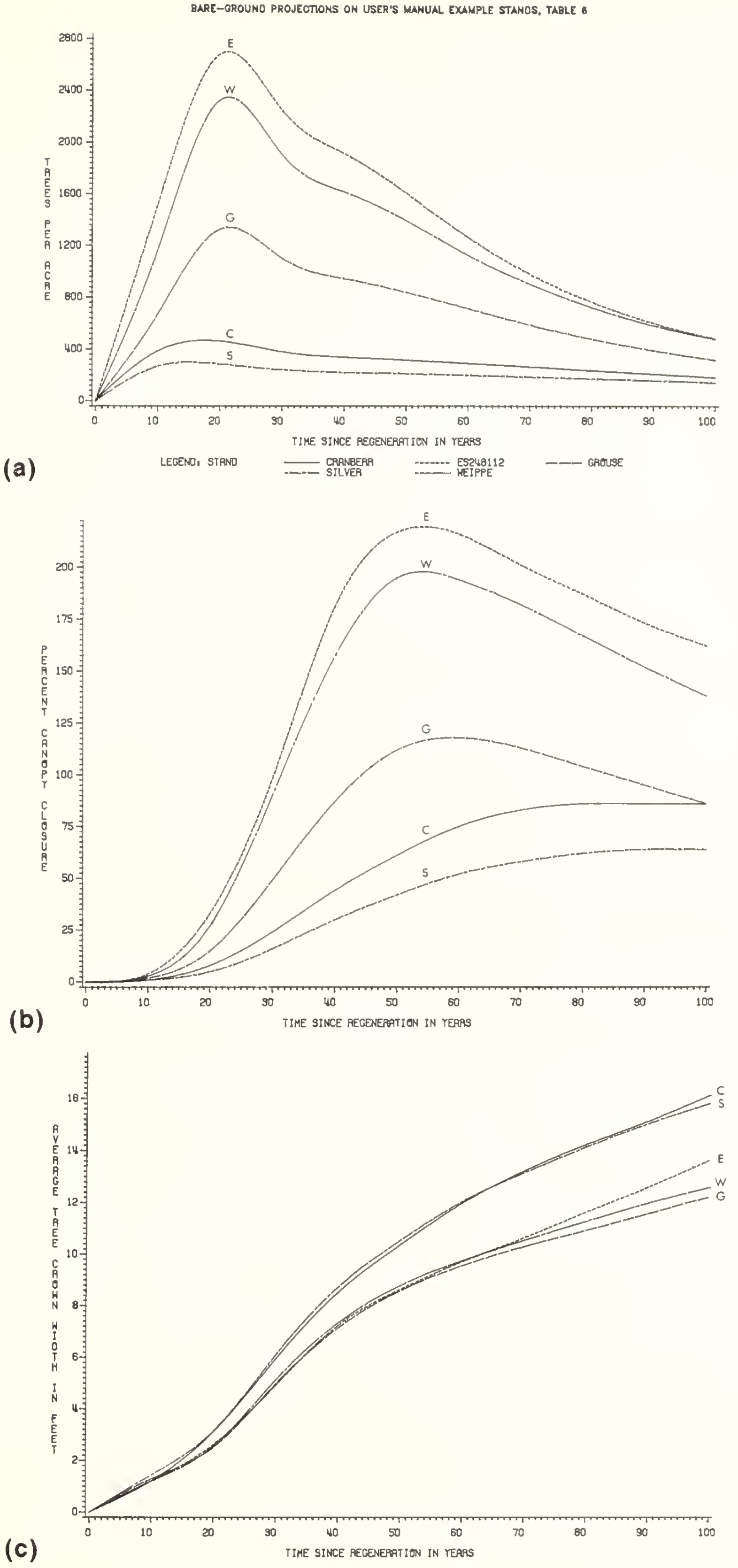
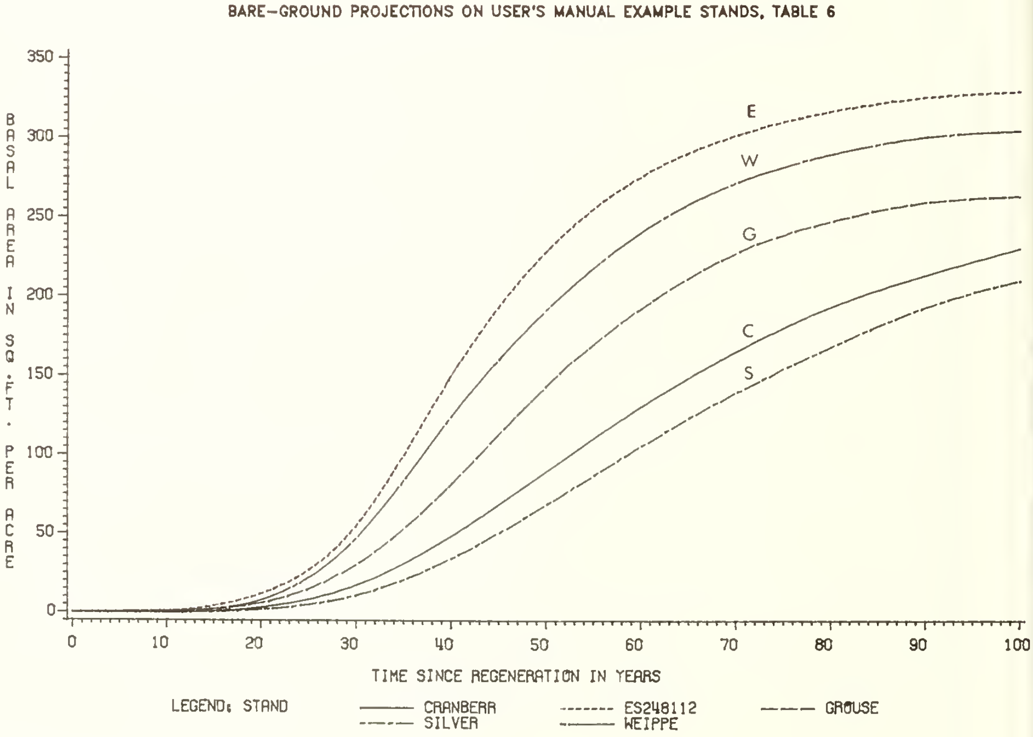


Figure 9.—Crown cover predictions for the regenerated stands in table 6: (a) predicted trees per acre versus time; (b) canopy closure versus time; (c) average tree crown width versus time.

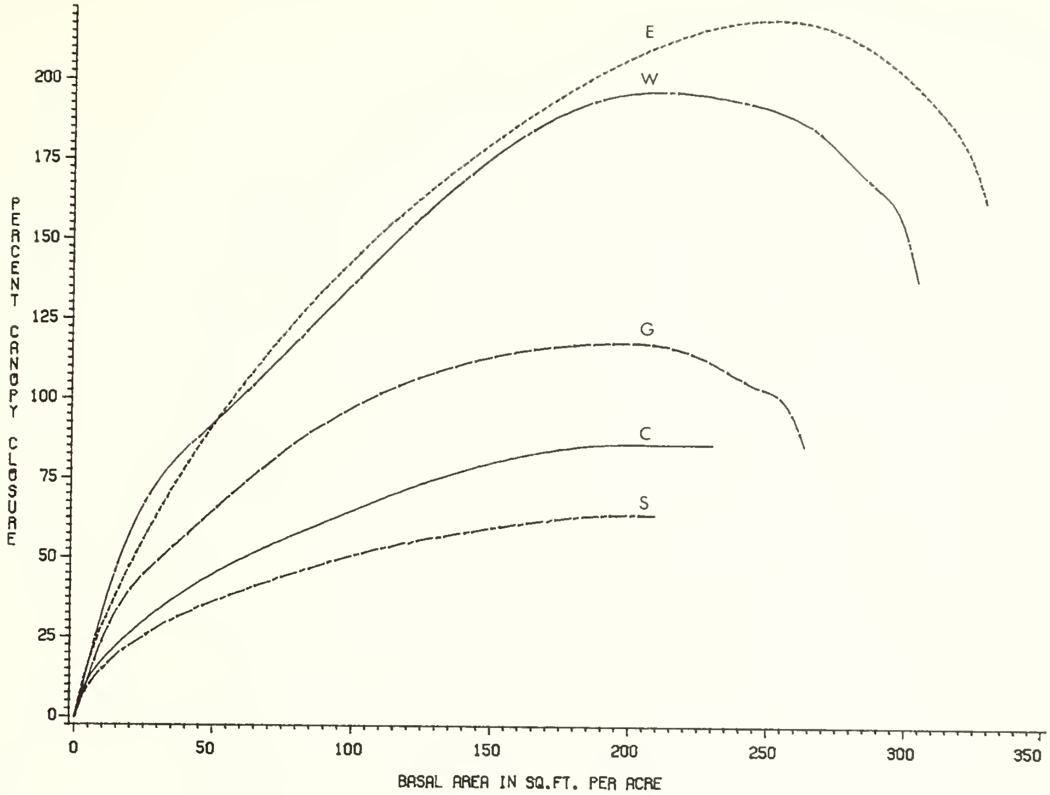
In stands where initial densities exceed about 400 trees per acre (E, W, G), average crown width increases continually through time as the number of trees in the stand decreases. Presumably, this is related to the amount of mortality and to the types of trees that are dying. As number of trees decreases, crown width on surviving trees continues to increase through time. In addition, more of the mortality in the older stands is accounted for by suppressed trees in the understory, leaving trees with relatively more vigorous crowns. Below initial densities of 400 trees per acre, there is little relationship between individual tree crown width and number of trees, or between percentage of cover and trees. Crown width increases throughout the length of the projection in the understocked stands, even though tree numbers remain relatively constant, indicating that stand density is not great enough to be limiting to individual crown development. Under apparent lack of competition for space, the tree crowns in stands C and S are free to expand. In general, the model predicts that crowns will be wider in stands that start out with more open conditions.

Figure 10 shows the relationship of overstory cover to stand basal area and the effect of competition between crowns. Canopy closure is monotonically increasing with increasing basal area in all stands. Canopy closure attains a maximum and then declines in the fully stocked stands, which reach maximum basal area and then level off (E, W, and G). Canopy closure levels off but does not begin to decline on stands that do not reach maximum basal area within the time frame of the projection (C and S). For a given basal area level, crown width is greater in the more open stands, this difference increasing throughout the projection.

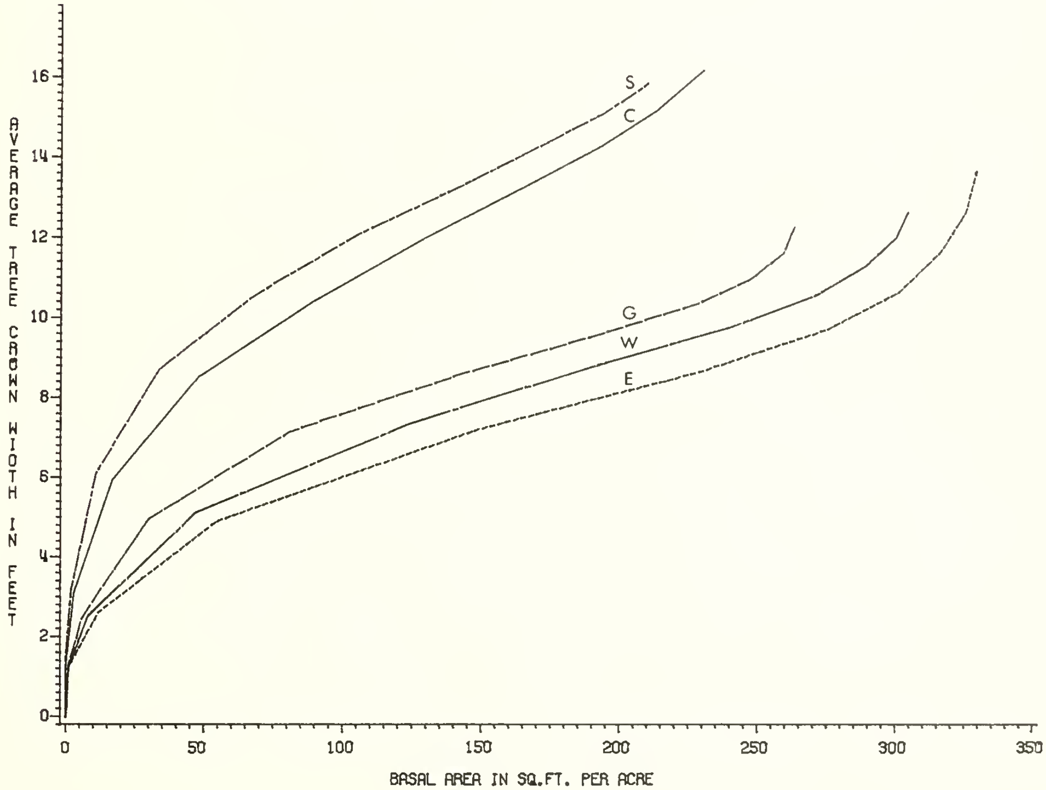


(a)

Figure 10.—(a) Stand basal area over time; (b) predicted canopy closure versus basal area; (c) average tree crown width versus basal area for the regenerated stands in table 6.


E
W
G
C
S
PERCENT CANOPY CLOSURE
0
25
50
75
100
125
150
175
200
0
50
100
150
200
250
300
350
BASAL AREA IN SQ.FT. PER ACRE

(b)


S
C
G
W
E
AVERAGE TREE CROWN WIDTH IN FEET
0
2
4
6
8
10
12
14
16
0
50
100
150
200
250
300
350
BASAL AREA IN SQ.FT. PER ACRE

(c)

Fig 10.—(Con.)

Crown Foliage Biomass.—Foliage biomass is predicted for individual trees using logarithmic linear regression equations (Moeur 1981). As in the crown width functions, there are different equation forms for trees less than 3.5 inches d.b.h and those 3.5 inches d.b.h. and larger. The equations predict foliage biomass from species, d.b.h., change in squared diameter, height, crown length, trees per acre, and relative diameter (d.b.h./quadratic mean stand diameter) for large trees, and from species, height, crown length, and trees per acre for small trees. Coefficients for the models are listed in tables 7 and 8.

Table 7.—Coefficients for estimating foliage biomass of trees 3.5 inches and larger (Moeur 1981): $\ln(\text{biomass}) = b_0 + b_1\ln(D) + b_2\ln(H) + b_3\ln(CL) + b_4\ln(DDS) + b_5\ln(TPA) + b_6\ln(DREL)$

Species[1]	Variable coefficients[2] Intercept b_0
WP	2.66607
L	1.75654
DF	2.70587
GF	3.11508
WH	2.65457
C	3.05935
S	3.30085
AF	3.06017
PP	2.45249
Other	2.62251

Variables	Variable coefficients
ln(D)	b_1 = 1.468547
ln(H)	b_2 = 1.07705
ln(CL)	b_3 = .69082
ln(DDS)	b_4 = .30885
ln(TPA)	b_5 = .14210
ln(DREL)	b_6 = .39924

---

[1] Species codes are given in table 3.

[2] Definition of variables:
D = diameter breast height (inches)
H = tree height (ft)
CL = crown length (ft)
DDS = change in squared diameter (in^2)
TPA = trees per acre
DREL = d.b.h/quadratic mean d.b.h.

Table 8.—Coefficients for estimating foliage biomass of trees less than 3.5 inches d.b.h. (Moeur 1981):
$\ln(\text{biomass}) = b_0 + b_1 \ln(H) + b_2 \ln(CL) + b_3 \ln(TPA)$

Species[1]	Variable coefficients[2] Intercept b_0	 ln(CL) b_2
WP	−1.94951	1.22023
L	−4.73762	1.98479
DF	−2.05828	1.25837
GF	−2.43200	1.60270
WH	−4.17456	2.00749
C	−2.24876	1.37600
LP	−3.13488	1.62368
S	−2.93508	1.96125
AF	−1.60998	1.32649
PP	−2.74410	1.58171
Other	−1.63387	1.35092

Variables	Variable coefficients
ln(H)	$b_1 = 0.40350$
ln(TPA)	$b_3 = .12975$

[1] Species codes are given in table 3.

[2] Definition of variables:
H = tree height (ft)
CL = crown length (ft)
TPA = trees per acre.

In general, the response patterns of total stand foliage biomass to trees per acre and basal area over time are similar to those for canopy closure (fig. 11). Total foliage is greater in the stands starting out with higher initial densities, peaking at 50 to 60 years, and then declining (stands E, W, and G). Stand foliage does not decline as sharply as does percentage of canopy closure near the end of the projection. Stands with low initial densities show gradually increasing values of foliage throughout the projection (C and S). Foliage production also depends on the species composition of the mature stands. Stands W and C have higher proportions of mature trees in grand fir, cedar, and Douglas-fir. These three species have greater predicted foliage values for a given set of stand conditions. Individual tree foliage development patterns through time are quite similar to those discussed for crown width.

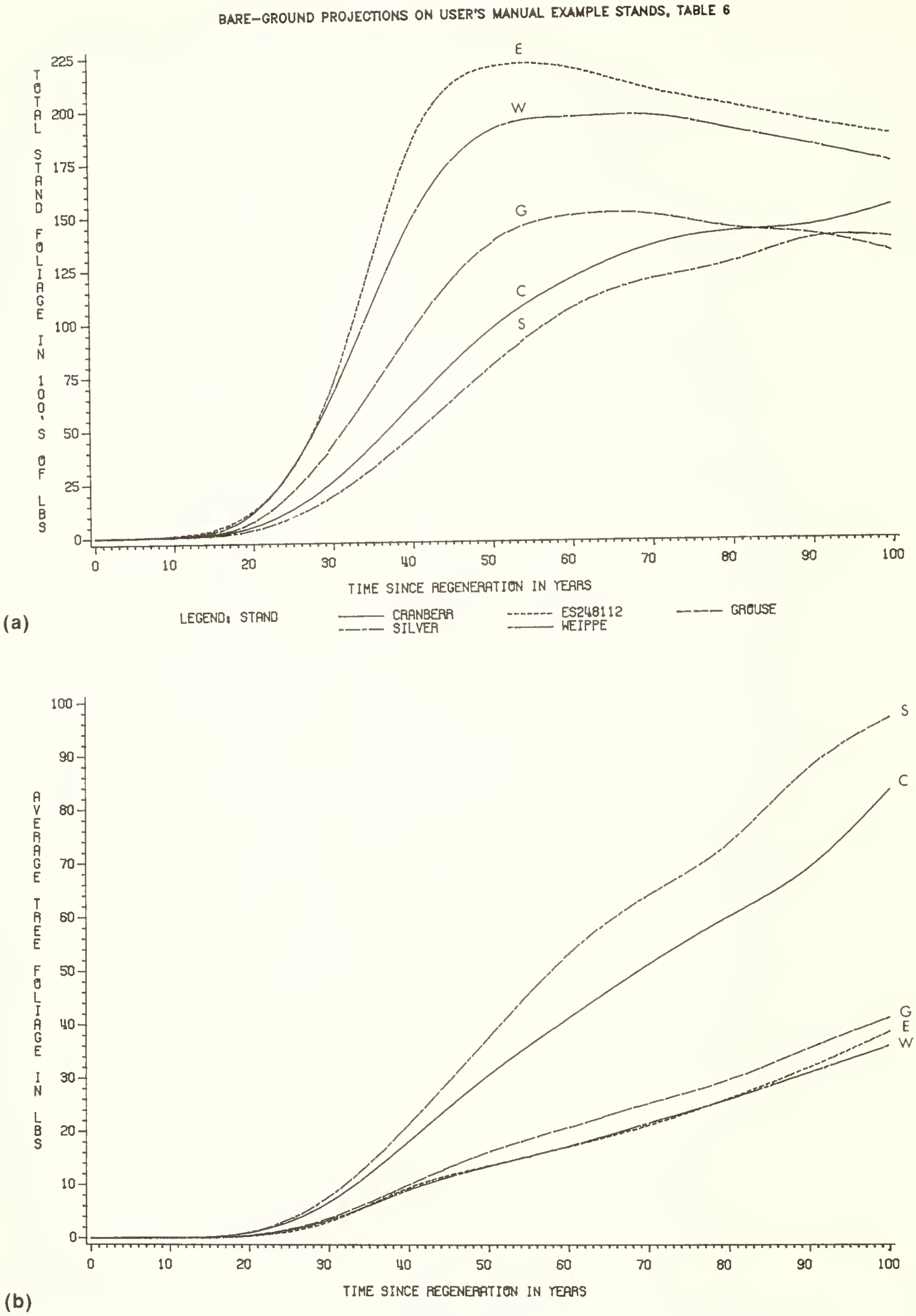
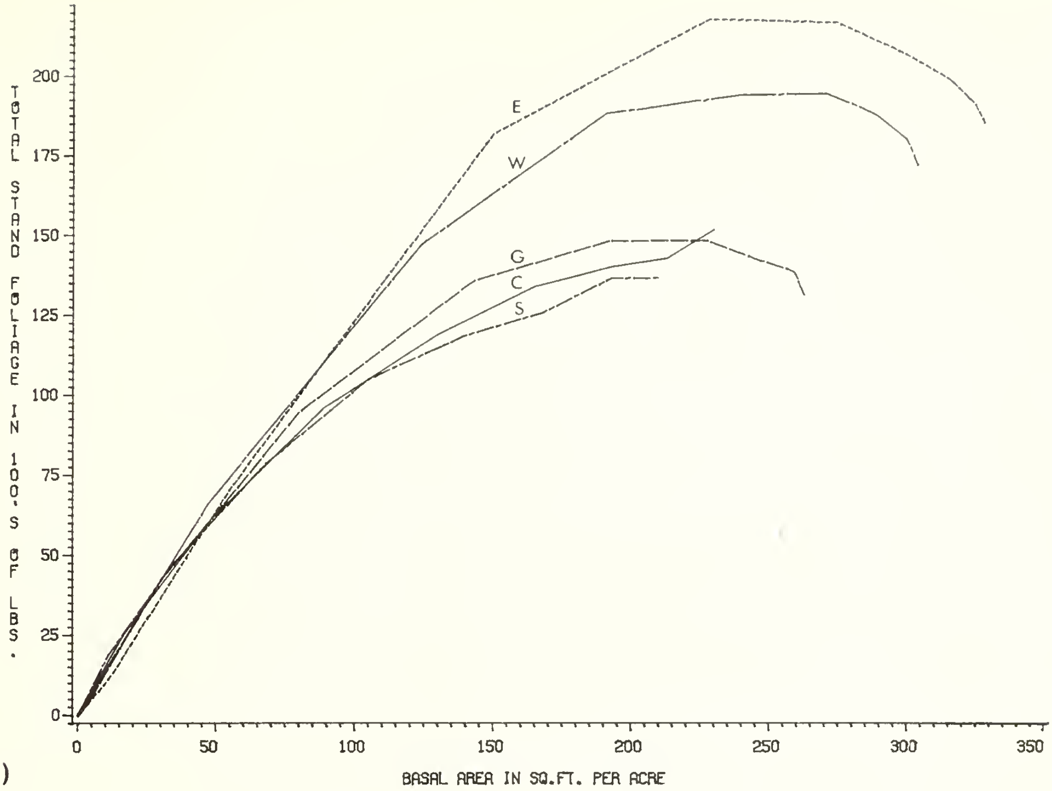
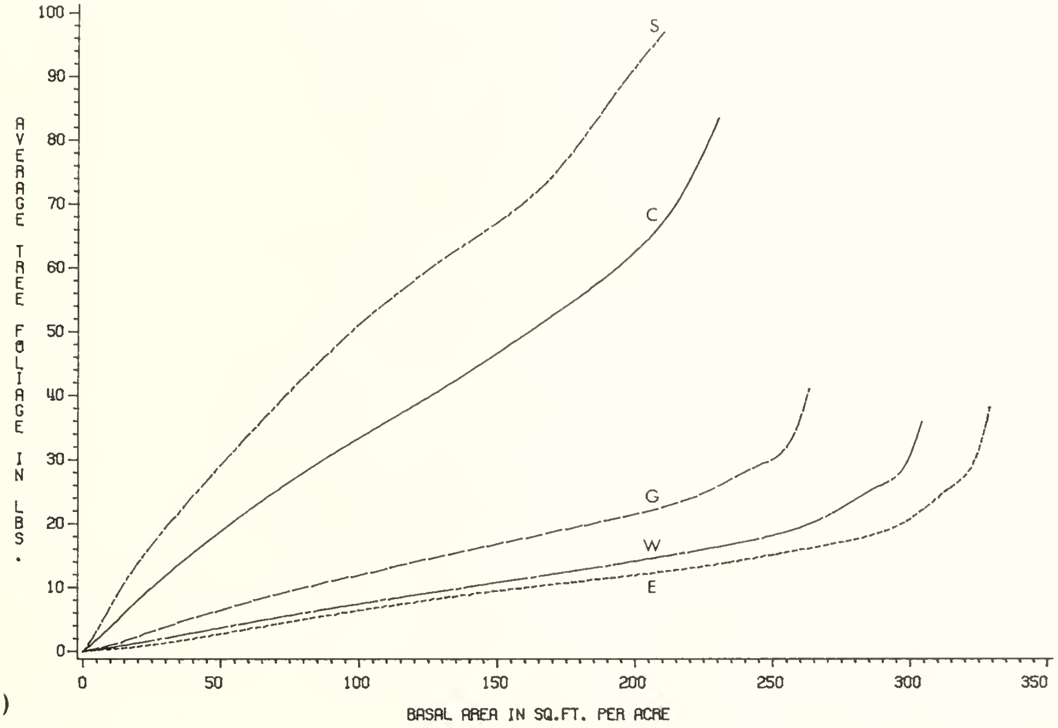


Figure 11.—(a) Predicted stand foliage and (b) tree foliage versus time; (c) stand foliage and (d) tree foliage versus stand basal area for the regenerated stands in table 6.



(c)



(d)

Figure 11.—(Con.)

Crown Shape.—Individual tree crown shape is predicted each projection cycle using a linear discriminant function (Moeur 1983). Tree crowns are classified into one of five shapes—circular, triangular, neiloid, parabolic, or elliptic—using species, height, d.b.h., crown length, crown radius, crown ratio, and trees per acre as discriminating variables. All tree crowns are assumed to have a circular bottom (fig.12).

Crown shape is used in three places in COVER. First, crown volume within vertical height classes in the stand is computed by summing sections of individual crowns, using formulas to integrate the five different solids of revolution in figure 12. Second, crown profile area within height classes is computed by summing the lateral area of individual crown sections (fig. 3b). Finally, tree foliage biomass is distributed within height classes by the proportion of frustum volume within height classes to total crown volume. An inner senescent cone is not considered; that is, foliage is assumed to be distributed uniformly throughout the crown.

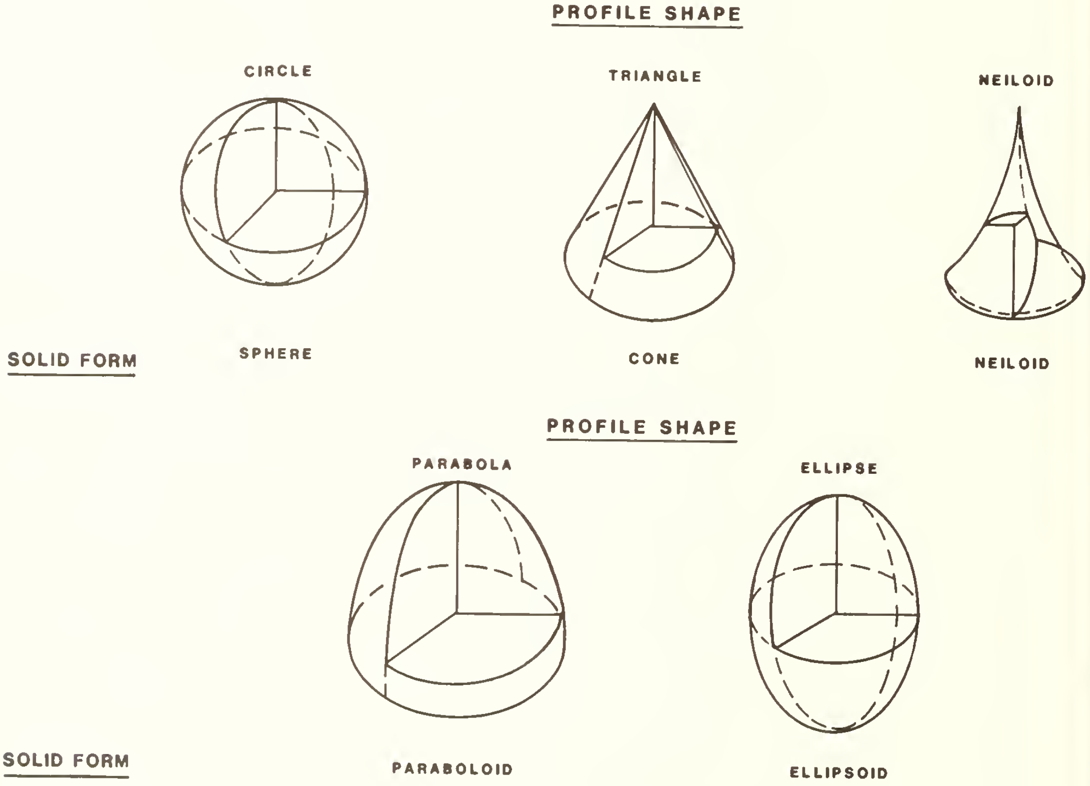


Figure 12.—Individual crowns are classified into one of five shapes in the CANOPY option (after Mawson and others 1976).

SHRUBS Submodels

The equations for predicting understory species relationships have been synthesized from the work of different people at different times. An early version of the SHRUBS extension, known as BROWSE (Scharosch 1980), incorporated studies on shrub development in grand fir, cedar, and hemlock habitat types conducted by Irwin and Peek (1979). In Prognosis 5.0, these relationships have been replaced by probability of occurrence equations for individual understory species developed by Scharosch (1984), and height and cover equations developed by Laursen (1984). Irwin and Peek's work was based on a subset (about 2,200 plots) of the data used by Laursen (1984) and Scharosch (1984). The expanded data (about 10,000 plots located in about 500 stands) include measurements from Douglas-fir and subalpine fir ecosystems as well as the original grand fir-cedar-hemlock types. Table 1 lists the species, range of habitat types, and sources of information for which predictions are currently made.

Inside the COVER program, the probability of any shrub cover on the site, and total shrub cover given that the probability is greater than zero, are predicted first. Then, probability of occurrence is calculated for each species individually using total shrub cover as a predictor. Next, heights are predicted for each species, also using total shrub cover. The species are sorted in order from tallest to shortest predicted height. Then, progressing down through the sorted list, individual species cover is calculated using predicted species height and the amount of overtopping cover. Species cover is weighted by species probability of occurrence. Finally, the cover values are summed and reported as total understory cover for the plot.

Total Shrub Cover.—Predictions for probability of any shrubs, and for total shrub cover, conditional on probability, are taken from Laursen (1984). The probability that shrub cover exists given the described stand conditions is calculated and reported in the summary display. This value expresses the proportion of 1/300-acre plots on which shrub cover is expected to be greater than zero. It is computed from a logistic regression model using slope, elevation, overstory basal area, habitat type, time since disturbance, and the interaction of time since disturbance and basal area. Next, total shrub cover is predicted using a lognormal linear regression model fit on plots in the original data where cover was actually present. Additional variables in this model are type of disturbance and the time and type of disturbance interaction. Total shrub cover predicted by Laursen's model for three hypothetical treatments is shown in figure 13.

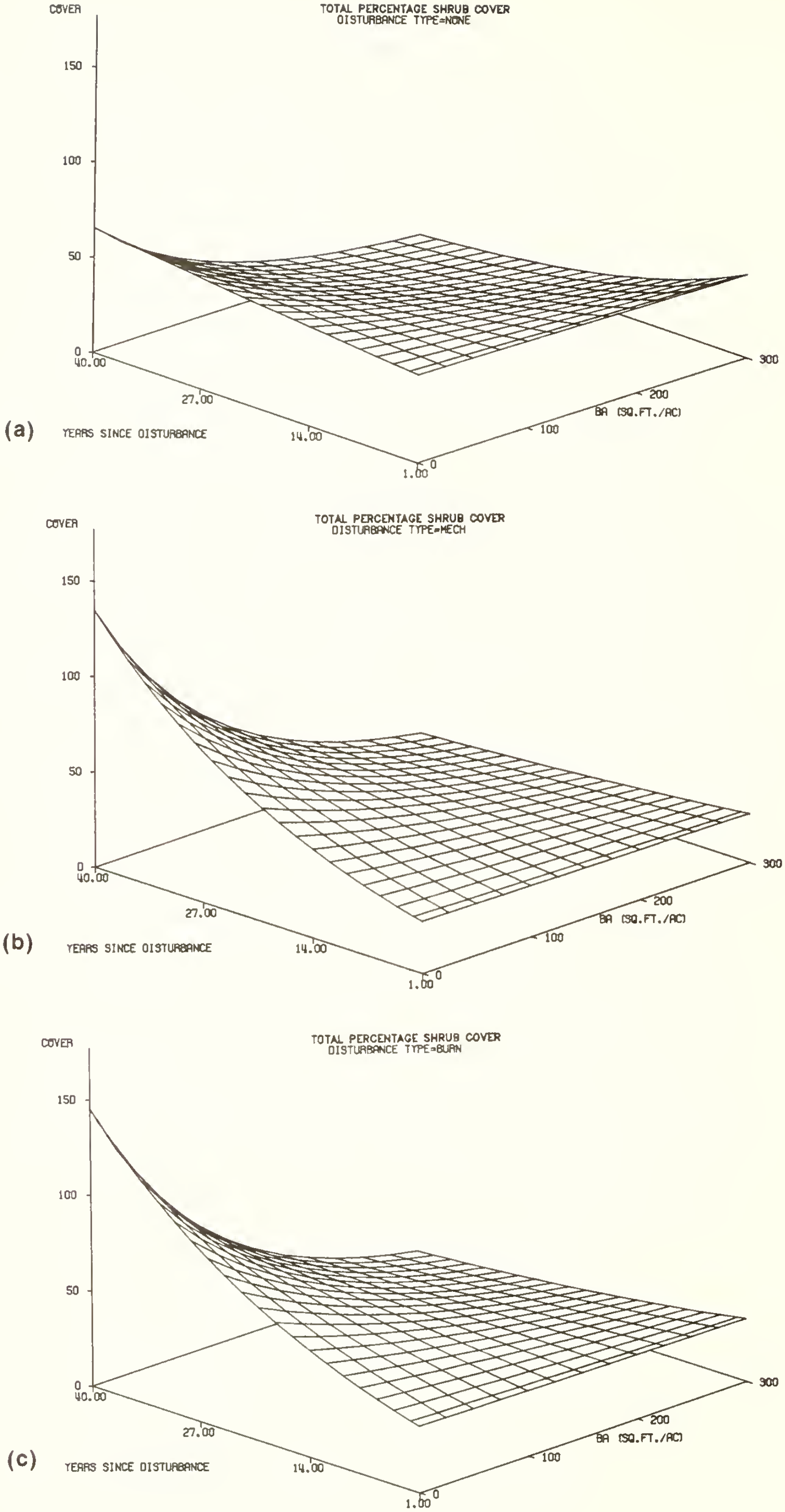


Figure 13.—Predicted total percent shrub cover relative to time since disturbance and overstory basal area following (a) no site preparation, (b) mechanical disturbance, and (c) burning. Variables held constant are slope = 0.25, elevation = 3,500 ft, habitat type = ABGR/CLUN (from Laursen 1984).

Table 9.—Variables used to predict probability of occurrence, height, and percentage of cover for the shrub species listed in table 1

Continuous variables

- Overstory basal area (ft^2/acre)
- Stand elevation (100's of feet)
- Elevation squared (10,000's of feet)
- Total percent shrub cover
- Slope (percent/100)
- Slope × sin(aspect)
- Slope × cos(aspect)
- Time since site disturbance (years)
- Overstory basal area × time since disturbance

Categorical variables

- Overstory climax species (includes habitat type):[1]
  - Douglas-fir (210, 220, 260, 310, 320, 330, 340, 380, 390, 395)
  - Grand fir (505, 510, 511, 515, 520, 525, 590)
  - Western redcedar (530, 540, 550)
  - Western hemlock (570)
  - Subalpine fir/mountain hemlock (620, 635, 645, 650, 670, 690, 705, 710, 720, 721, 730, 790, 830)
- Understory climax union (includes habitat type):[1]
  - ABGR/CLUN, COOC, XETE, LIBO, ABLA/STAM, ABLA/LUHI (510, 511, 520, 590, 635, 690, 710, 830)
  - THPL series (530, 540, 550)
  - Tall shrub (260, 390, 515, 525, 645, 670, 720, 721, 730)
  - Low shrub (310, 340, 380, 395, 505, 705)
  - TSHE/CLUN, ABLA/CLUN (570, 620)
  - Grasses (210, 220, 320, 330, 650, 790)
- National Forest grouping:
  - Boise, Payette
  - Nezperce
  - Clearwater, Coeur d'Alene, Lolo, St. Joe
  - Panhandle, Colville, Kaniksu, Kootenai
- Physiography:
  - Bottom
  - Lower slope
  - Midslope
  - Upper slope
  - Ridge
- Type of site disturbance:
  - None
  - Mechanical
  - Burn
  - Road
- Type of disturbance × overstory basal area
- Type of disturbance × time since disturbance

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[1] See table 2 for habitat type code definitions.

Species Probability of Occurrence.—Predicted probability of occurrence equations for the species in table 1 are from Scharosch (1984). He uses a logistic multiple regression model to predict species occurrence from the continuous and categorical variables in table 9. The logistic model produces a sigmoidal curve with predicted values restricted to the closed interval (0,1). Representative responses of predicted probability of occurrence are plotted in figure 14.

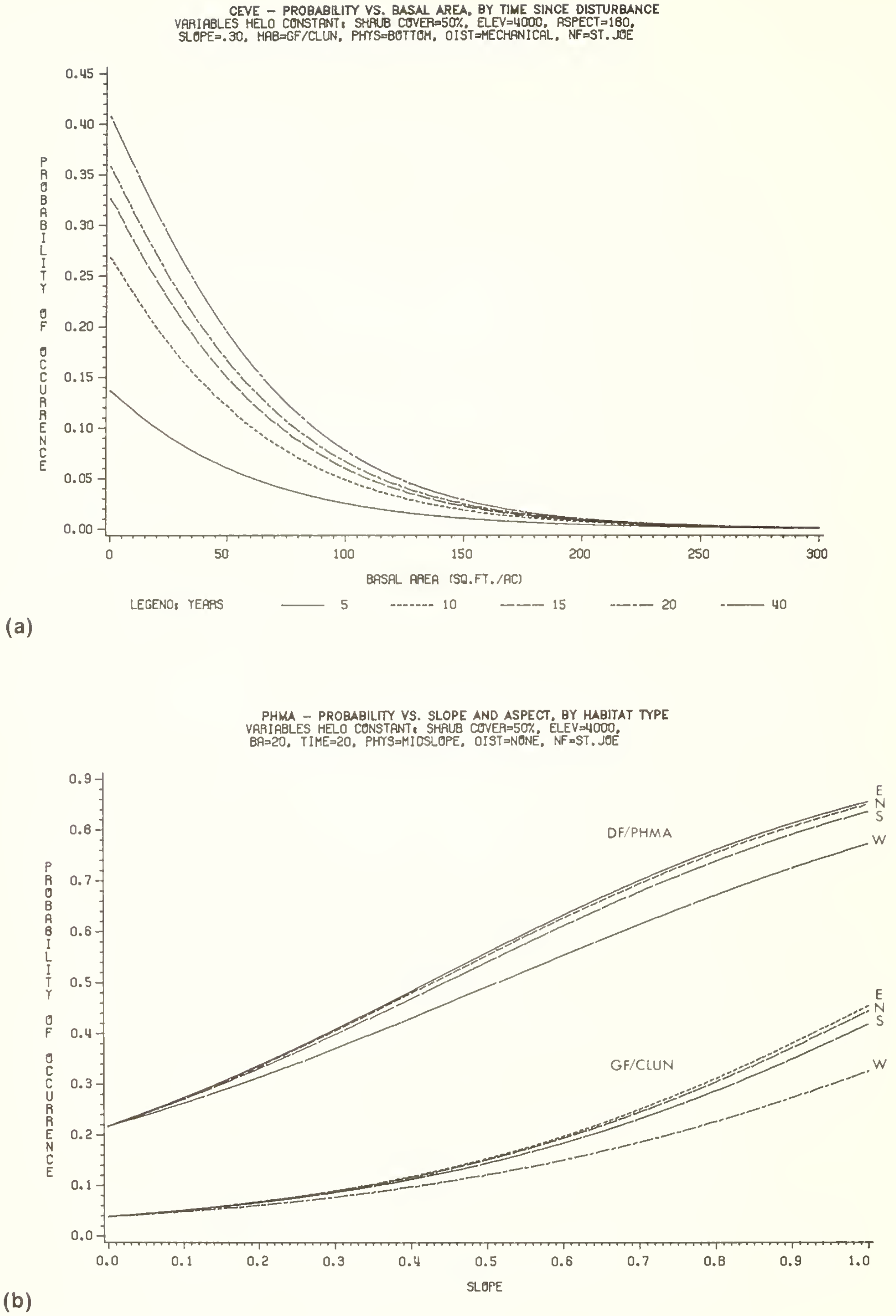
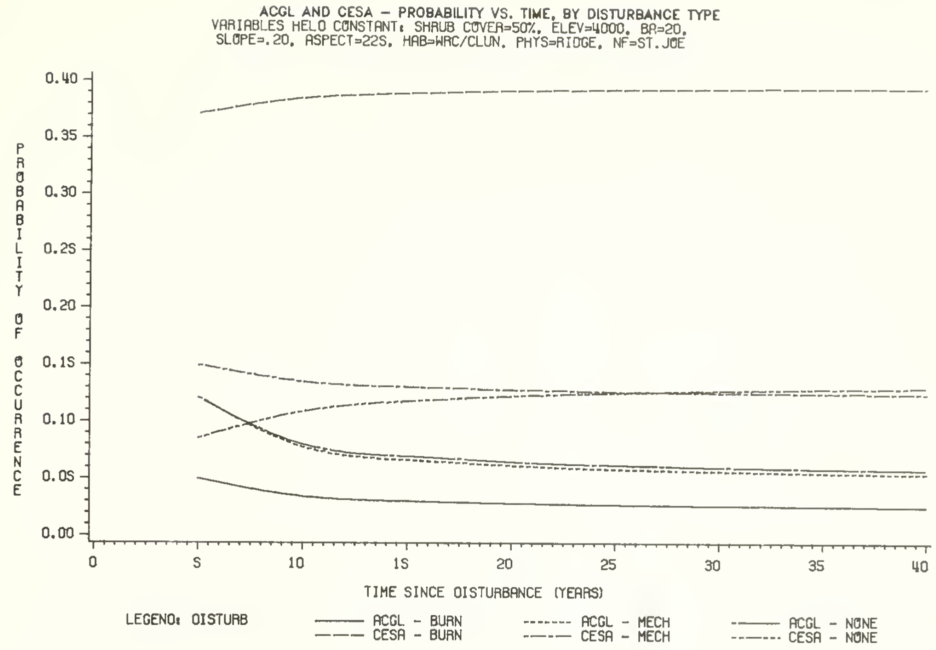


Figure 14.—(a) Predicted probability of occurrence across a range of overstory basal area and time since disturbance for Ceanothus velutinus; *(b) predicted probability of occurrence by slope and aspect for* Physocarpus malvaceus *on PSME/PHMA and ABGR/CLUN habitat types; (c) predicted probability of occurrence by disturbance type for* Ceanothus sanguineus *and* Acer glabrum *(from Scharosch 1984).*



(c)

Fig 14.—(Con.)

Individual Species Height.—Laursen (1984) uses either linear or lognormal regression model forms to predict the average heights of individual species in the described stand. Model forms differ between species, but most contain time since disturbance, overstory basal area, and predicted total shrub cover and its residual (the difference between observed and predicted values when an observed value is supplied by the user) as independent variables. Various transformations of the independent variables in table 9 are included to represent other site and treatment effects. The equations are detailed in Laursen's paper. Representative response patterns of predicted height over time and stand basal area are plotted in figure 15.

Individual Species Cover.—Percentage of cover by species follows lognormal or logistic distributions, conditional on the presence of the species in the stand (Laursen 1984). Cover for most species is a function of predicted species height and its residual (observed minus predicted when observed values are supplied), overtopping by taller species (the percentage of predicted cover above current height), time since disturbance, type of disturbance, overstory basal area, and site conditions. Representative plots of the response of species cover to basal area over time are shown in figure 16.

Twig Production and Dormant Season Shrub Biomass.—Total current year's twig production in twigs per square foot and total dormant season aboveground shrub biomass in pounds per acre are computed only for the 16 species noted in table 1 and only on ABGR/CLUN, THPL/CLUN, and TSHE/CLUN habitat types (Irwin and Peek 1979). Twig production is a log-linear regression equation dependent on time since disturbance, overstory crown competition factor (CCF) (Krajicek and others 1961), and habitat type. Shrub biomass is also log-linear, predicted from time since disturbance and CCF.

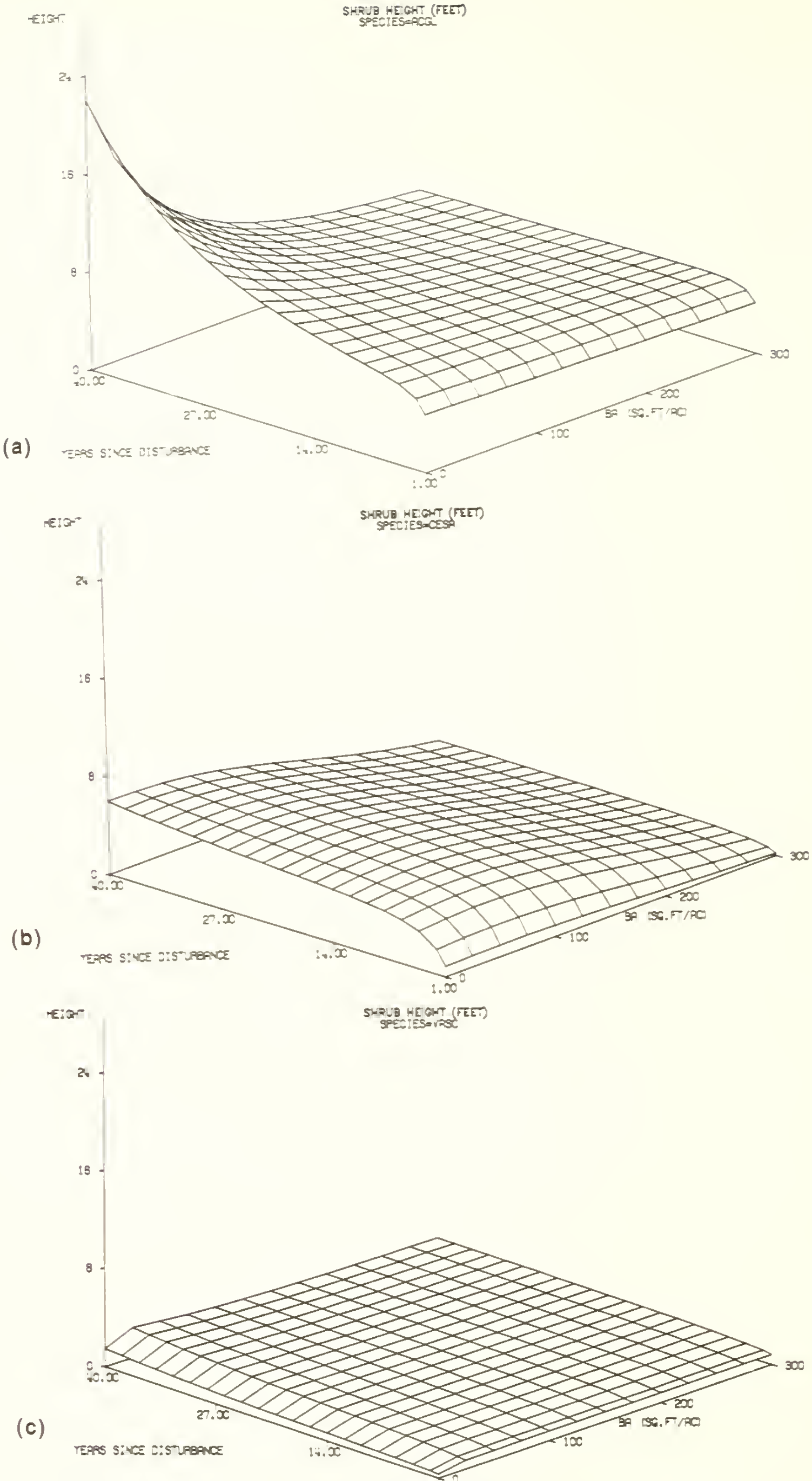


Figure 15.—Predicted shrub height relative to overstory basal area and time since disturbance for (a) Acer glabrum, *(b)* Ceanothus sanguineus, *and (c)* Vaccinium scoparium. *Variables held constant are slope = 0.25, aspect = east, elevation = 3,500 ft, habitat type = ABGR/CLUN, physiography = midslope, disturbance type = burn, forest = St. Joe (from Laursen 1984).*

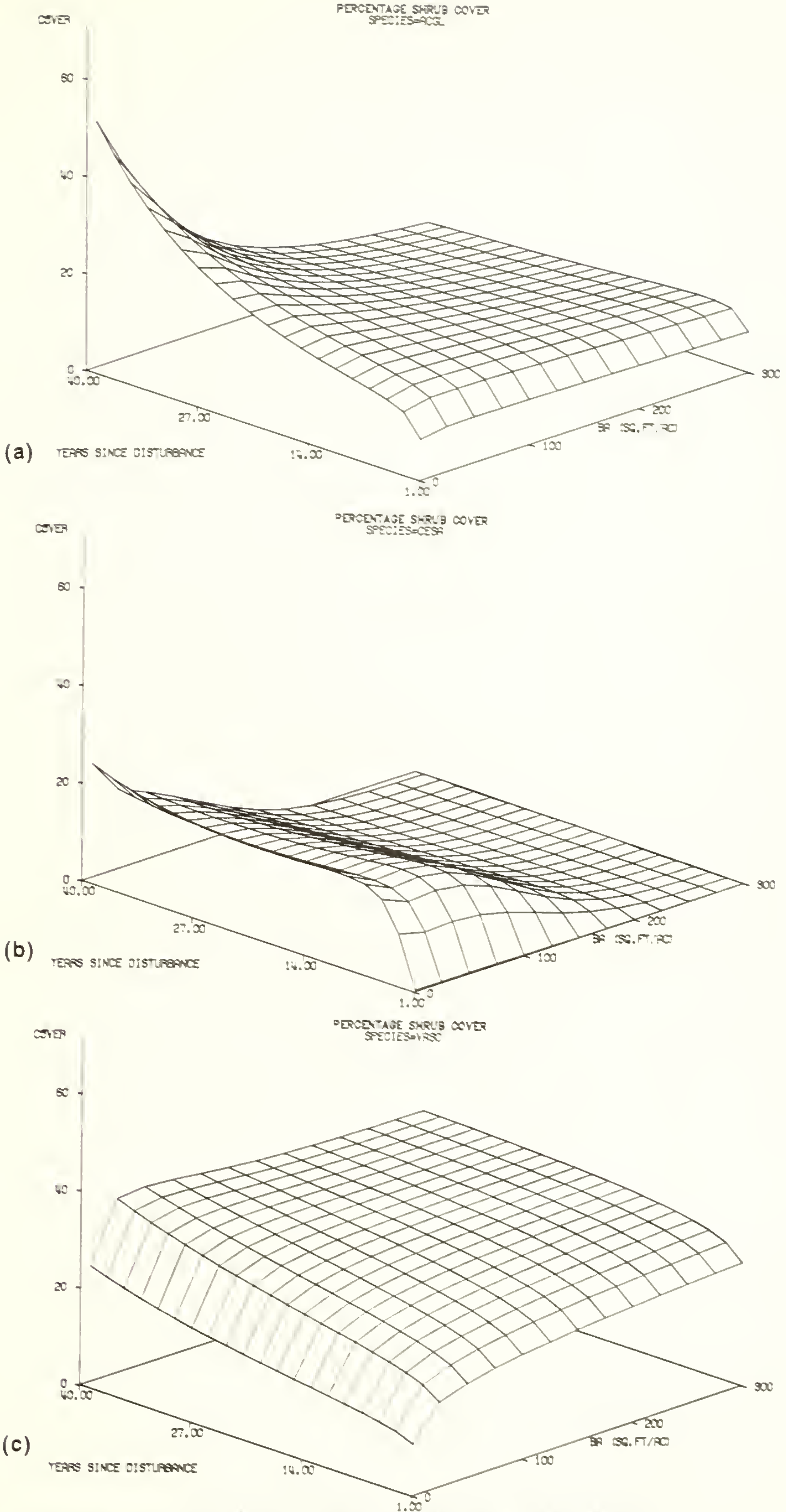


Figure 16.—Predicted shrub cover relative to overstory basal area and time since disturbance for (a) Acer glabrum, *(b)* Ceanothus sanguineus, *and (c)* Vaccinium scoparium. *Variables held constant are slope = 0.25, aspect = east, elevation = 3,500 ft, habitat type = ABGR/CLUN, physiography = midslope, disturbance type = burn, forest = St. Joe (from Laursen 1984). Values shown are for predicted cover prior to multiplication by probability of occurrence.*

Stand Successional Stage

One subprogram within the COVER extension computes and displays a "stand successional code" that is related to the vertical structure of both shrubs and trees (Peterson 1982). The purpose of the classification is to provide a basis for relating wildlife use to a particular type of stand that now exists, or that will result from management. The codes are listed in table 10.

The classification is a function of time since stand disturbance, crown competition factor (CCF), average tree height, a selectively defined "average" stand diameter, and average tall shrub height (average predicted height, weighted by predicted cover for *Acer glabrum*, *Alnus sinuata*, *Amelanchier alnifolia*, *Ceanothus sanguineus*, *Ceanothus velutinus*, *Cornus stolonifera*, *Holodiscus discolor*, *Prunus emarginata*, *Prunus virginiana*, *Salix* spp., *Sambucus* spp., and *Sorbus* spp.).

To compute average stand diameter, a series of logical tests determines whether the stand is even-aged, two-storied, or all-aged based on the distribution of trees per acre and percentage of cover by 10-ft height classes. For even-aged stands (a stand in which 90 percent of the total canopy closure is accounted for by trees within a 30-ft height range), the root mean square diameter of the stand is used as the average diameter. For two-storied stands (the two most dense 20-ft layers must be separated by 20 ft or more), the root mean square diameter for the most dense 20-ft layer only is used as the average diameter. For all-aged stands (the most dense 10-ft layer contains less than 20 percent of the total canopy closure, the three most dense 10-ft layers contain less than 50 percent, etc.), the average diameter is taken to be the root mean square diameter of the three most dense 10-ft layers. The stand is then classified according to the scheme in table 10. Note that restrictions for stages 1 to 4 are of the type "CCF less than 30 **or** average tree height less than 1 ft." For stages 5 and 6, there is a "percent shrub cover" **or** "average tall shrub height" restriction.

Table 10.--Classification scheme for assigning stand successional stage code (after Peterson 1982)

Condition	Recent disturbance (1)	Low shrub (2)	Medium shrub (3)	Tall shrub with no conifers (4)	Tall shrub with few conifers (5)	Tall shrub with mostly conifers (6)	Sapling timber (7)	Pole timber (8)	Mature timber (9)	Old-growth timber (10)
Time since stand disturbance (years)	<5									
Crown competition factor	<30 or	<30 or	<30 or	<30 or	30-50	50-100	>100	>100	>125	>100
Average tree height (ft)	<1	<1	<1	<1	<5	>5				
Percent shrub cover	<25			>70	>50 or	>30 or				
Average "tall shrub" height (ft)	<1.0	<2.5	2.5-5.0	>5.0	>5.0	>5.0				
"Average" stand diameter (inches)							<4	4-11	11-24	>24

USING THE COVER EXTENSION AS A MANAGEMENT TOOL

The general comments in this section are intended to guide the user in applying information produced by the combined Prognosis/COVER model in a broader planning context. There is little specific COVER output that directly interprets wildlife, hydrologic, or insect pest relationships. Instead, it is up to the user to interpret the information specific to his or her application. An important criterion in developing COVER was to make it broad enough in design for many applications, but primarily to link vegetation changes with nontimber resources. COVER can be a useful tool for decisionmaking when combined with knowledge of a specific resource ecology and its relation to vegetation management systems.

Wildlife Habitat Applications

Many of the shrub and tree cover development values produced by COVER can be related to wildlife habitat. An example stand projection illustrates how displays generated from COVER values can be used to compare vegetation changes and alternative treatment effects on wildlife habitat. The example presented is a stand that was inventoried in 1984 at 145 years of age. Initial stand density is 459 trees per acre, composed of an understory of Engelmann spruce beneath a sparse overstory of Douglas-fir, western larch, and grand fir. The stand is on the Nezperce National Forest, ABGR/VAGL habitat type, northeast aspect, 50 percent slope, at 5,800 ft elevation. Two silvicultural treatments were simulated and compared. In the first, the lower and upper portions of the diameter distribution were removed in cycle 1, leaving 60 Douglas-fir, larch, and spruce trees per acre, with diameters between 18 and 25 inches. At the end of the second cycle, natural regeneration was predicted to be 780 trees per acre, composed of 60 percent grand fir, 25 percent Douglas-fir, and 15 percent spruce. Twenty years after the initial thin, all trees greater than 7 inches d.b.h. were removed, and the regenerated stand was grown to age 100. This prescription is referred to as "two-step shelterwood." The second prescription, "clearcut," cut all trees in the stand in cycle 1. Natural regeneration at the end of the second 10-year cycle was 450 trees per acre, of which 65 percent were grand fir, 30 percent Douglas-fir, and 5 percent larch. This stand was then grown to age 100.

Excellent discussions of cover-forage ratios, hiding cover, and thermal cover requirements for deer and elk are presented by Thomas and others (1979a). Thermal cover is defined to be any stand of coniferous trees 40 ft or more tall, with an average canopy closure exceeding 70 percent. Figure 17 compares canopy closure and tree height for the two prescriptions. The shelterwood stand reaches a top height of 56 ft and 79 percent canopy closure at age 60. Beyond 60 years, the canopy is nearly fully closed, providing thermal cover throughout the rest of the projection. The clearcut stand supplies less adequate thermal cover, at an older age (80 years and beyond).

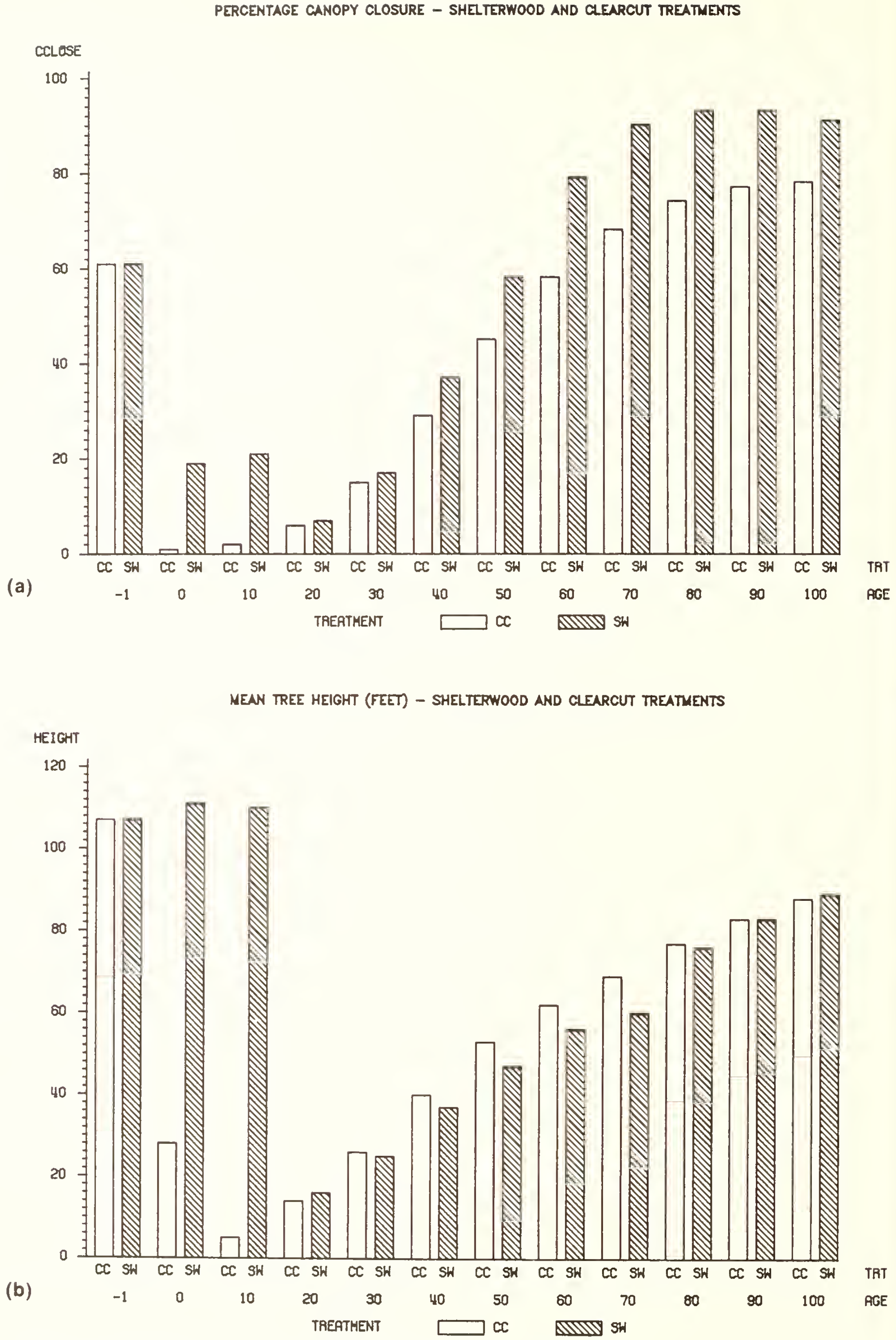


Figure 17.—Thermal cover compared for shelterwood and clearcut prescriptions for the wildlife example stand: (a) stand canopy closure versus stand age following initial thinning in 1984; (b) average tree height versus stand age.

Hiding cover (defined by Thomas and others [1979b] to be vegetation capable of hiding 90 percent of a standing adult elk from view at a distance equal to or less than 200 ft) can be compared between alternative treatments by looking at shrub cover, crown profile area in the first 10 ft of height in the stand, the sum of stem diameters, and trees per acre (fig. 18). Predicted shrub cover is 44 percent for the shelterwood treatment and 43 percent for the clearcut treatment following the 1984 thinning. It increases to 52 percent at age 30 in the clearcut stand. In the shelterwood stand, shrub density decreases to 31 percent at age 20, and then the overstory removal triggers a second wave of increasing shrub cover. By age 40, shrub density is again equal in the two treatments, at about 45 percent cover.

In general, hiding cover in stems and tree crowns is greater in the shelterwood treatment, primarily because regeneration is more successful. In both treatments, area in crowns in the lower 10 ft of the stand begins at nothing at stand age 0 and increases to a maximum at about 30 or 40 years. After 40 years, the lower canopy level begins to grow above the height where it can be considered effective hiding cover. Beyond 60 years, stem area contributes more to hiding cover, and crown profile area contributes less.

Figure 19 illustrates how canopy development predicted by COVER may be displayed graphically through time. The vertical distribution of crown profile area is shown for the two prescriptions immediately before thinning in 1984, and at several points in time following harvest. Similar stand profiles could be drawn to represent numbers of trees, percentage of canopy closure, crown volume, or foliage density by height. These values may be useful in relating bird habitats to the structure of vegetation (for example, see Langelier and Garton in press b; Peterson 1982) or the "life form" association with stand successional stage proposed by Thomas and others (1979b).

The wildlife example presented here shows how stem area, crown profile area, and related values can be interpreted as thermal and security cover for big game. Foliage-height profiles and crown volumes by height classes are also useful statistics in analyzing bird habitat relationships. The interpretation of canopy and shrub height and density into wildlife cover is hypothetical for the example presented and, of course, depends on knowledge of actual stand conditions.

Vegetation management for wildlife use requires interdisciplinary knowledge of the interactions of vegetation, site and topographic conditions, silvicultural options, and road and harvest operations. The combined Prognosis/COVER model can provide information about the condition of the vegetation, including species composition, size, and distribution of both the overstory and understory. Thomas (1979) points out that habitat use does not follow some arbitrary step function, but that wildlife species use vegetation despite what wildlife biologists define to be less than optimum conditions (70 percent canopy closure for thermal cover, for example). COVER values are expressed as continuous through time, rather than as threshold values, so that the user may evaluate their implications for wildlife habitat management. COVER output can be written to a disk file (by using the second parameter on the COVER keyword) for later summarization and graphical display.

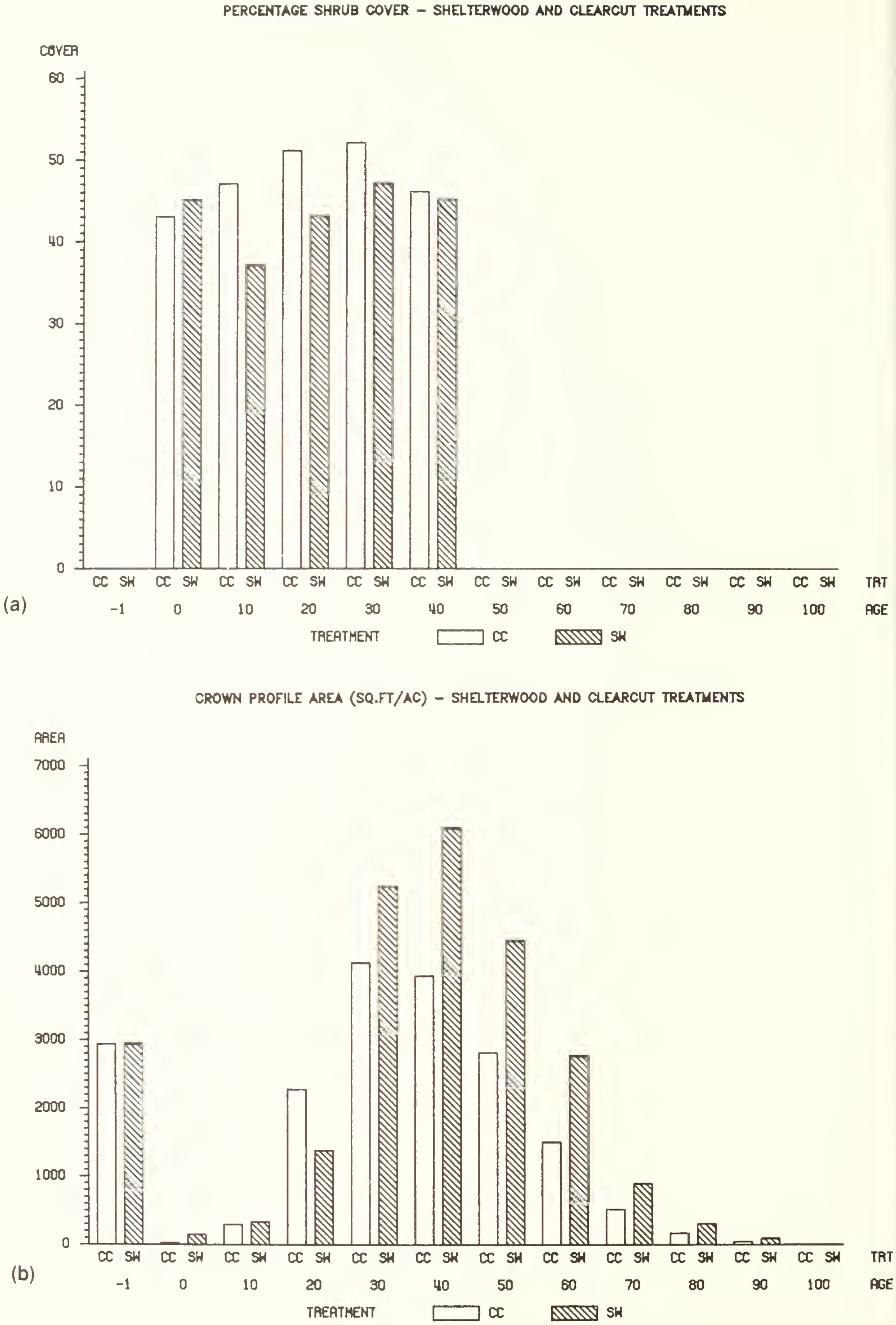
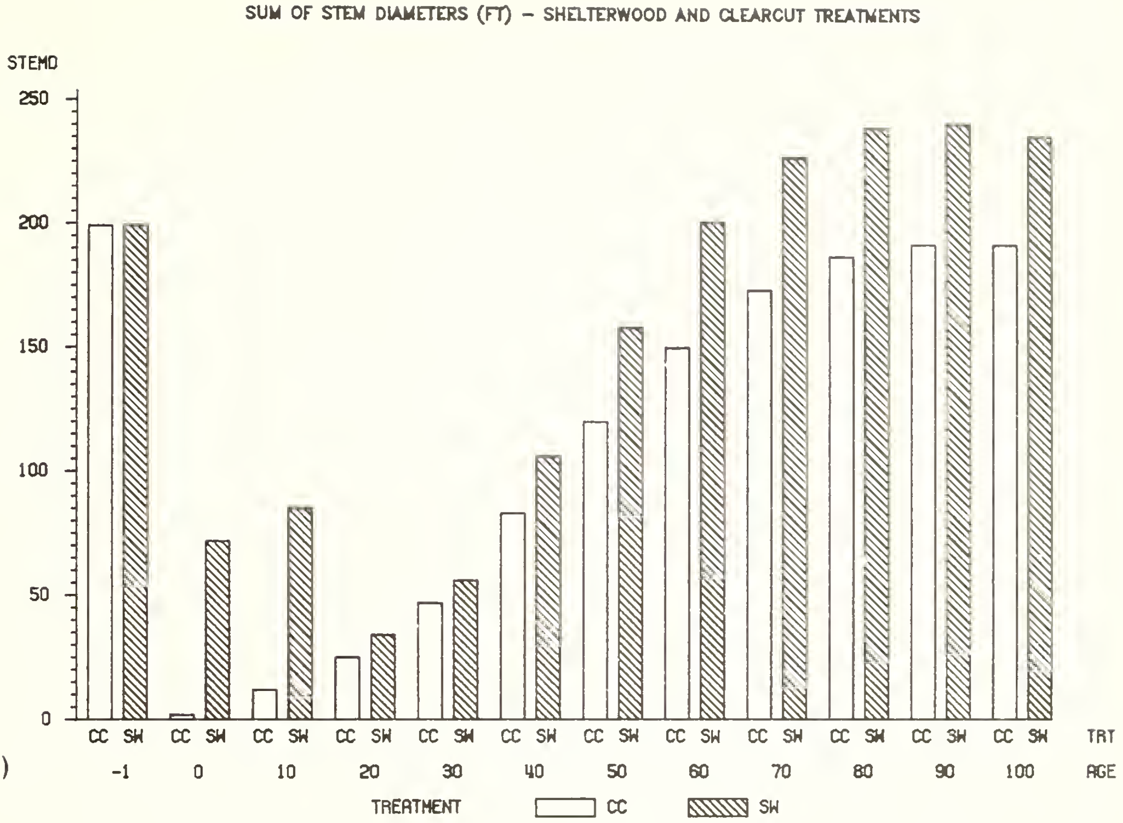
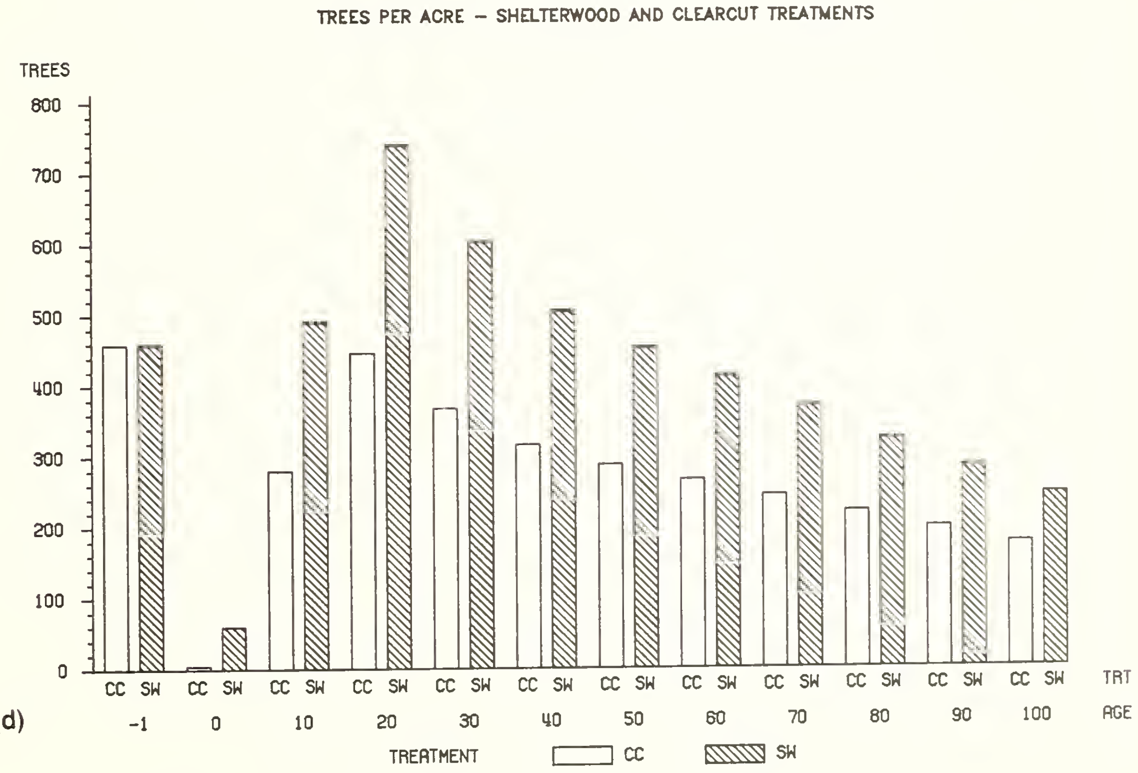


Figure 18.—Hiding cover compared for shelterwood and clearcut prescriptions for the wildlife example stand: (a) percentage shrub cover versus stand age following initial thinning in 1984; (b) crown profile area i the lower 10 ft of the stand versus stand age; (c) sum of stem diameters versus stand age; (d) number of trees versus stand age.



(c)



(d)

Figure 18.—(Con.)

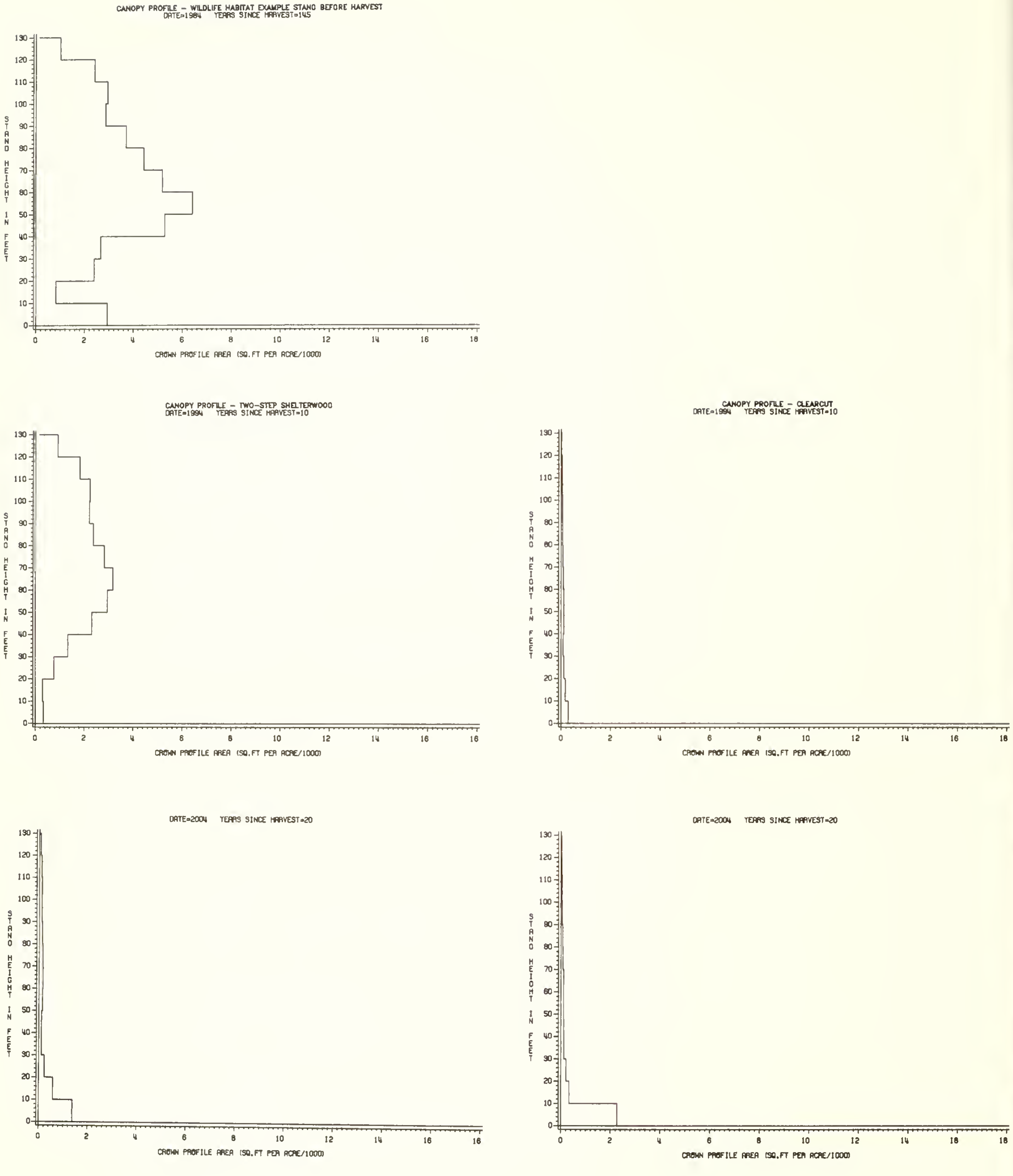


Figure 19.—The development through time of crown profile area by stand height for the wildlife habitat example.

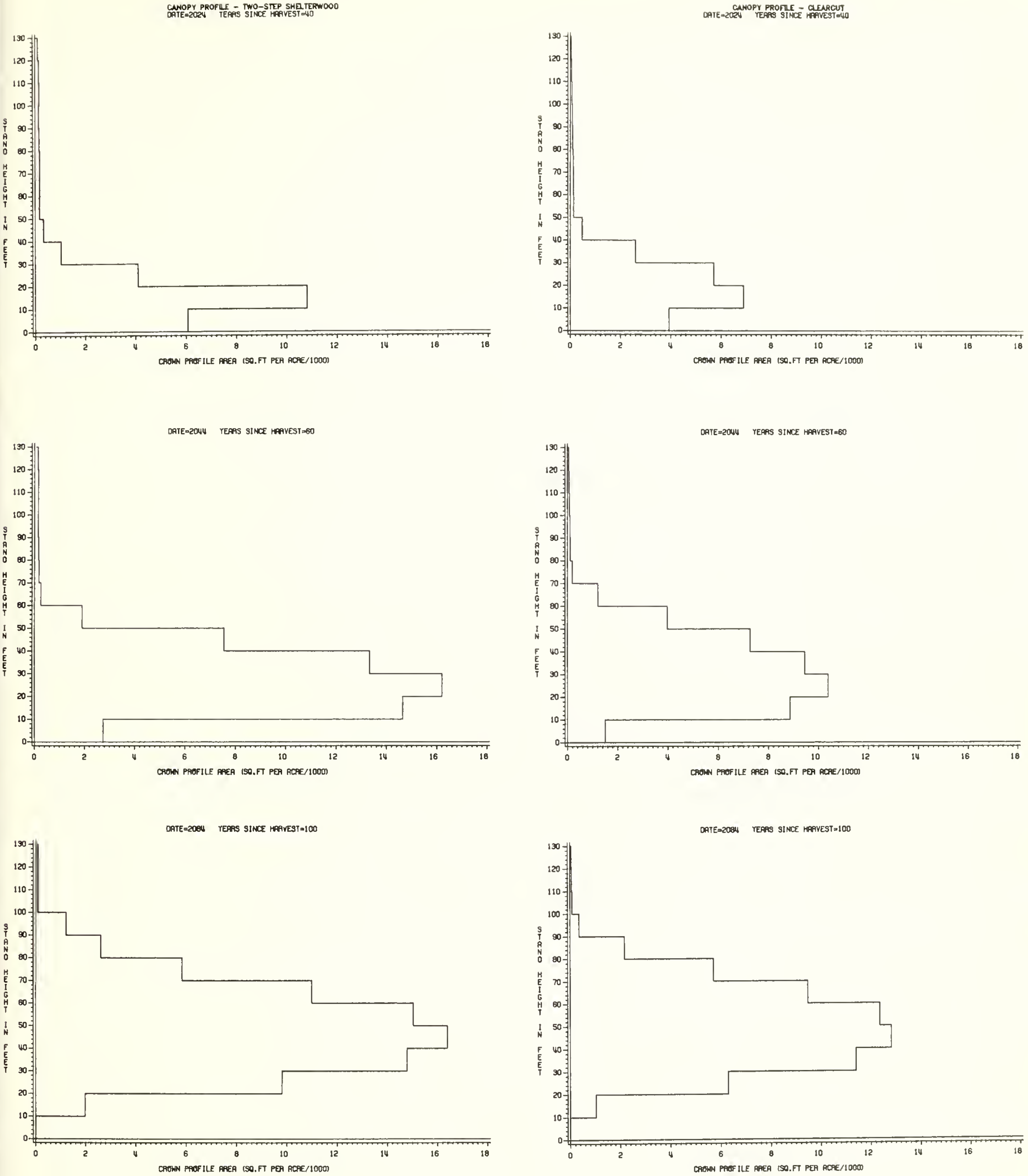


Figure 19. (Con.)

Hydrologic Applications

The COVER extension can be used to link natural or human-made vegetation changes to watershed impacts, primarily through predicted canopy closure and shrub cover values. The sum of cover conditions across stands in a watershed can be expressed as the percentage of ground exposed to precipitation and runoff following management.

Forest Insect Pest Modeling Applications

The COVER relationships for conifer foliage biomass and crown shape are currently being used in the Western Spruce Budworm Outbreak Model (Sheehan and others in preparation). The foliage equations predict total potential foliage biomass on undamaged trees. Assumptions about the partitioning of foliage by age classes within branches, the distribution of foliage within crowns, and the predicted effects of defoliation on future foliage production are all components of the western spruce budworm (WSBW) model. These relationships help predict insect damage to trees through availability of food and pattern of larvae dispersal vertically in the stand.

Succession Modeling and Planned Improvements

The combination of understory development and vertical and horizontal canopy development relationships comprising the COVER extension represents a framework for which quite detailed successional trends can be displayed through time. Planned future studies will more explicitly link the shrubs component to the regeneration system (Ferguson and others 1985) and small tree development models (Wykoff 1985) by modeling effects of shrub competition on small conifer establishment and growth rates.

A second improvement planned for COVER includes the option of making predictions on individual sample points within a stand, thus allowing a heterogeneous site to be represented in greater resolution. This will improve the prediction of shrub conditions, allow reporting of within-stand variance statistics, and provide a measure of the spatial distribution of overstory and understory cover.

Work is progressing on a graphical display link that shows the vertical and horizontal relationships of trees and shrubs through time. The display is in the form of a "lollipop" diagram in which each of several figures of a certain height and shape represent different types of tree and shrub records in the stand.

The Prognosis/COVER program incorporates models that are specific to certain species and conditions prevalent in the Northern Rocky Mountains, but it is also a general system that can be calibrated to local conditions. As shrub and crown data specific to other areas and habitat types become available, new relationships can be incorporated into the model to expand the range of predictions.

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APPENDIX: SUMMARY OF COVER KEYWORDS

Category	Keyword	Keyword use and associated parameters	Default parameter or conditions
Program control	CANOPY	Compute canopy cover statistics.	None
	COVER	Invoke the COVER extension; always the first keyword record.	
		field 1: Cycle in which COVER calculations begin.	1
		field 2: Dataset reference number for COVER output.	18
	END	Last keyword record; return control to main program.	
	SHRUBS	Compute shrub statistics.	
		field 1: Number of years since stand disturbance.	Stand age (STDINFO card), or 3 years
		field 2: Habitat type code.	Stand habitat type code (STDINFO card)
		field 3: Physiographic type code.	2 (Lower slope)
		field 4: Disturbance type code.	1 (None)
Calibration	SHRBLAYR	Enter shrub calibration values by shrub layer.	No calibration
		fields 1,3,5: Average height (ft) of three shrub layers.	
		fields 2,4,6: Average cover (%) of three shrub layers.	
	SHRUBHT	Enter shrub height calibration values by species.	No calibration
		Up to four supplemental records: Species code and height (ft) in consecutive 10-column fields.	
	SHRUBPC	Enter shrub cover calibration values by species.	No calibration
		Up to four supplemental records: Species code and cover (%) in consecutive 10-column fields.	
Output control	DATELIST	Print date of last revision for COVER model subprograms and common areas.	None
	DEBUG	Request printout of COVER calculations for tree and shrub list.	
		field 1: Cycle in which debug output is to be printed.	Print in all cycles
	NOCOVOUT	Suppress the canopy cover statistics display.	Display printed
	NOSHBOUT	Suppress the shrub statistics display.	Display printed
	NOSUMOUT	Suppress the canopy and shrubs summary display.	Display printed
	SHOWSHRB	Select additional shrub species to be displayed.	Print nine species which account for most cover.
		Supplemental record: Species codes right justified in six consecutive 10-column fields.	

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Moeur, Melinda. COVER: a user's guide to the CANOPY and SHRUBS extension of the Stand Prognosis Model. General Technical Report INT-190. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station; 1985. 49 p.

The COVER model predicts vertical and horizontal tree canopy closure, tree foliage biomass, and the probability of occurrence, height, and cover of shrubs in forest stands. This paper documents use of the COVER program, an adjunct to the Stand Prognosis Model. Preparation of input, interpretation of output, program control, model characteristics, and example applications are described.

KEYWORDS: stand structure, crown width, crown shape, canopy closure, foliage biomass, shrub cover, shrub height, shrub occurrence, stand simulation

The Intermountain Research Station, headquartered in Ogden, Utah, is one of eight Forest Service Research stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

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Forest Service

Intermountain
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Wildlife Management Implications of Petroleum Exploration and Development in Wildland Environments

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MARIANNE BROMLEY earned a B.S. degree in fisheries and wildlife biology from Iowa State University and an M.S. in resource geography from Oregon State University. She has participated in research on Canada geese, arctic water birds, bald eagles, and coots in Alaska, Oregon, and South Carolina. This report, based on her master's thesis, was conducted cooperatively with the Intermountain Research Station, USDA Forest Service. She is presently involved in wildlife research and writing in Canada's Northwest Territories, located at Yellowknife.

RESEARCH SUMMARY

This report describes the sequence of events, their characteristics, and the associated environmental disruptions involved in the exploration, development, and production of petroleum. The potential effects of environmental disruptions on wildlife behavior, populations, and habitat are evaluated, drawing on a review of the literature, supported by a selective, annotated bibliography. Potential effects are numerous and varied. Impact severity is site specific and depends on the sensitivity of the species affected, the nature of the environmental disruption, habitat characteristics, and the availability and condition of alternative habitat. The major wildlife groups affected by petroleum activities are ungulates, carnivores, water birds, upland birds, and raptors. Possible approaches to minimizing adverse effects on wildlife are presented, including changes in management of petroleum projects, personnel, and wildlife habitat and populations.

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Cover: Antelope in front of oil well.

Wildlife Management Implications of Petroleum Exploration and Development in Wildland Environments

Marianne Bromley

INTRODUCTION

The current domestic energy policy of becoming as self-sufficient as possible is encouraging rapid increases in petroleum exploration and development. Public lands are receiving much attention as "our last unexplored frontier for oil and gas" (Dibble and Hamilton 1979). There is pressure to reevaluate laws, regulations, and policy directives that restrict exploration and development on many Federal lands, including existing and proposed Wilderness Areas, RARE II lands, critical wildlife habitats, and other undeveloped wildlands (American Petroleum Institute 1981; Rogers 1981; Schumacher and others 1979). Oil and gas leases were applied for on more than three dozen Wilderness Areas before the terms of the Wilderness Act ended leasing in 1984. Approval of leases has been recommended for several Wilderness Areas in the West (Nice 1982). Considerable conflict is occurring between oil and environmental interests in the Rocky Mountain Overthrust Belt, a geological formation believed to have great oil and gas potential, but underlying much of the wildlands in Wyoming, Idaho, Utah, and Montana (Hamilton 1978; Kline 1981; Whipple 1977).

The rapid rate of resource development dictates that resource managers become familiar with the potential problems inherent in energy development and begin to implement guidelines to minimize adverse effects on the wildland environment (Burger and Swensen 1977). One of the major problems associated with energy development concerns the potential effect of petroleum development activities on wildlife, especially those species dependent on a wildland environment. Construction of roads, drilling pads, and pipelines, the influx of people and machinery, and the development of construction camps and boom towns are but a few of the activities that create disruptions potentially threatening to wildlife not habituated to high levels, or the presence, of human activities.

Managers faced with the task of protecting wildlife in such a situation are handicapped by the lack of readily available information on the responses of wildlife to various development activities. Although research into the effects of disturbances specific to the petroleum industry is limited, numerous studies have been completed describing the effects of other human activities that may result in environmental disruptions (noise, increased traffic) similar to those caused by petroleum exploration and development operations. Results of this work, however, are dispersed in the scientific literature. This report was prepared with the belief that a review and synthesis of this research would be useful to managers, especially while awaiting results from studies dealing more specifically with the effects of petroleum development on wildlife.

Purpose and Objectives

The purpose of this report is to provide resource managers with a compilation of background information useful in the development of guidelines and/or management strategies designed to minimize adverse effects of petroleum exploration and development on wildlife in wildland environments. It is not intended for use in deciding whether or not to allow development, but rather to aid in the identification of wildlife/land use conflicts, to increase the manager's awareness of the implications of development, and to provide information that may facilitate minimization of harmful effects in the event that development in sensitive areas is approved. It does not consider the esthetic problems that may be associated with development of wildland areas. The major objectives of the report are:

1. To familiarize resource managers with the sequence of events, major activities, and associated environmental disruptions involved in the exploration, development, and production of petroleum.
2. To provide an overview and evaluation of the potential effects of these disruptions on wildlife behavior, habitat, and populations by presenting an annotated bibliography of literature on effects of land use activities.
3. To present a general description of possible approaches to minimizing these effects (mitigation, management strategies).

For the purpose of this paper, "environmental disruption" is defined as a human-caused modification of the environment that may ultimately result in adverse effects on wildlife. It includes changes of a physical nature, and changes in the level or type of activities in an area. A disruption results from one or several development activities and represents the mechanism through which wildlife is affected. It is considered here to be a common denominator allowing comparison between the effects of various land use activities and potential effects of petroleum extraction activities.

Scope

Petroleum development activities may result in a wide range of effects on the physical environment—soil, vegetation, water, air—but these are addressed here only as they directly relate to terrestrial wildlife. The subjects of oil spills, pollution, and major effects on aquatic habitats, although potentially serious, are addressed only in a very general way because such information would easily fill a separate paper. The range of species discussed was determined by the available literature and includes primarily ungulates, carnivores, raptors, and waterfowl. Songbirds, shorebirds, and furbearers are addressed more briefly. Discussion of fish and other aquatic organisms is beyond the scope of this report.

Because of its broad geographic coverage the report may be used in many areas. The majority of published research to date has been conducted in the Arctic, and more recently in the Rocky Mountains and several north-central and eastern States. Results of arctic studies constitute a large part of this paper, but are reported only when relevant to other geographic areas. Discussion of problems specific to arctic development—such as the need to import all equipment and workers, the special requirements of permafrost construction, and the vulnerability and low productivity of northern biological systems—is of interest to a relatively limited audience and has already received good coverage in other publications (Hanley and others 1980; Klein 1973; USGS 1979). It is therefore not repeated here.

This paper is based on a review of literature published in scientific journals, magazines, government publications, private industry reports, and a few unpublished papers. It represents a synthesis of data covering a wide variety of wildlife species, geographical locations, and land uses. Legitimate concerns exist over (1) the validity of generalizing or extrapolating from one situation or species to another, and (2) the validity and practicality of using behavioral responses as measures of effect, as they have not been demonstrated to relate directly to changes in productivity or survival of a population (Jingfors and Gunn 1981). Without specific project descriptions and complementary species studies, however, managers must mainly rely on general findings from past studies and general wildlife observations when dealing with immediate problems and develop measures to minimize effects of current development on wildlife. The present rate of development precludes the possibility of long-term, species- and site-specific research that might relate individual and population responses and provide more definitive conclusions concerning the effects on wildlife. Many authors cited in this paper specify that results apply only to circumstances under which the study was conducted, and request that caution be used in making generalizations from their research.

Specific information presented in this paper is intended as background data to supplement local inventory and research data. Resource managers will need to make judgments, based on professional expertise and awareness of the limitations described, in extrapolating from results reported in this paper to their particular situations. Managers should be aware that new research on the effects of development on wildlife is continually being completed, and they should be ready to alter management actions, if necessary, as future research results become available.

Much of the published research on wildlife-petroleum relations has been conducted in the arctic. Here, caribou graze near an oil derrick.

EXPLORATION AND DEVELOPMENT ACTIVITIES

This section describes the general sequence of operations and types of activities involved in petroleum exploration, development, and production. The degree and nature of development activity is site-specific to each well or oil field, and depends on such factors as geology and reservoir characteristics, terrain conditions, and existing access and support facilities. Although environmental disruptions are common to all phases of development, their magnitude may vary and is also strongly dependent on site-specific conditions (Hanley and others 1980). Nonetheless, general oil field practices can be outlined. The sequence of operations normally progresses through five phases: (1) preliminary exploration, (2) exploratory drilling, (3) development, (4) production, and (5) reclamation/abandonment.

Table 1 summarizes activities involved during each phase of operation. Table 2 shows the environmental disruptions resulting from each of these activities. The major sources used throughout the following sections describing oil field operations are Amerada Hess Corp. 1980; Hanley and others 1980; Overthrust Industrial Association 1981a; USDA 1981a, 1981b; USDI 1979, 1981a, 1981b. Additional references are cited as necessary.

Table 1.—Phases of petroleum development and activities occurring during each phase

Activity	Development phase				
	Explore	Drill	Develop	Produce	Abandon
Ground surveys	x				
Seismic trail clearing	x				
Seismic wave production/recording	x				
Clearing/grading right-of-way		x	x		
Road construction	x	x	x	x	
Mobilization of trucks/equipment	x	x	x	x	x
Site development (clearing/grading)		x	x	x	
Drill pad construction		x	x		
Excavation of storage/mud pits		x	x		
Drilling and related activities		x	x		
Water supply		x	x		
Borrow pit excavation		x	x		
Wellhead/pump unit installation			x		
Construction of process/treatment/ storage facilities				x	
Installation of flow lines				x	
Erection of power lines				x	
Communication system development				x	
Operation of process/treatment facilities				x	
Pipe stringing				x	
Trenching and pipe installation				x	
Pipe burial and backfill				x	
Maintenance and inspection				x	x
Accidents		x	x	x	x
Secondary recovery				x	
Air support	x	x	x	x	x
Worker accommodations		x	x	x	x
Increase in local population		x	x	x	
Development of ancillary industry				x	
Well plugging					x
Site restoration/revegetation					x

Table 2.—Potential environmental disruptions resulting from oil field activities

Activity	Potential environmental disruption						
	Noise	Aircraft	Human intrusion	Traffic and access	Structures and facilities	Alteration of vegetation/ land	Harmful substances
Ground surveys			x	x			
Seismic trail clearing	x		x	x		x	
Seismic wave production/ recording	x		x				
Clearing/grading right-of-way	x		x	x		x	
Road construction	x		x	x	x	x	
Mobilization of trucks/ equipment	x			x			x
Site development (clearing/grading)	x		x			x	
Drill pad construction	x		x			x	
Excavation of storage/mud pits	x		x		x	x	x
Drilling and related activities	x		x				
Water supply	x		x	x	x		
Borrow pit excavation	x		x			x	
Wellhead/pump unit installation	x				x		
Construction of process/ treatment/storage facilities	x		x		x	x	
Installation of flow lines	x				x	x	
Erection of power lines	x				x	x	
Communication system development	x				x	x	
Operation of process/ treatment facilities	x		x				
Pipe stringing	x		x		x		
Trenching and pipe installation	x		x			x	
Pipe burial and backfill	x		x		x	x	
Maintenance and inspection			x				
Accidents						x	x
Secondary recovery	x		x				
Air support	x	x					
Worker accommodations			x				
Increase in local population			x	x			
Development of ancillary industry			x			x	
Well plugging	x		x				
Site restoration/revegetation	x		x				

Preliminary Exploration

The main purpose of this phase is to locate and obtain detailed information on geologic structures with the potential for producing oil and gas. It can be conducted on leased or unleased lands. Initially, geologic literature, surface maps, aerial photos, low-altitude reconnaissance flights, and higher altitude magnetic and gravity survey flights are used to search for the presence of structures that may contain oil and gas traps or reservoirs. More detailed ground surveys, and sampling of surface and subsurface rocks, follow at promising sites. Environmental disruptions through this stage are minimal, although small crews with light vehicles must be present and some off-road travel may be necessary in areas without existing access roads or trails.

If these surveys continue to indicate the probable occurrence of petroleum accumulations at a site, seismic prospecting normally ensues. This procedure involves the artificial generation of shock waves and the subsequent recording, by special detectors, of the times necessary for the waves to be reflected back to the surface from rock interfaces at various depths. The results indicate the depths of specific formations. The energy source and sensors are located along straight seismic lines laid out in a grid.

Two general types of seismic operations are possible, their uses determined by the difficulty of access and the sensitivity of the environment:

1. Operations that use heavy, truck-mounted equipment for drilling shot-holes, recording, and in some cases generating seismic waves. Shock waves may be produced by several methods:

— explosives loaded into 50- to 200-ft drilled holes and detonated.

— "thumper" trucks drop a heavy weight to the ground several times in succession along a predetermined line.

— truck-mounted vibrator pads that vibrate the earth at intervals along a line.

A typical operation may use 10 to 15 people and five to seven trucks. If access is inadequate, a network of temporary roads and trails may have to be constructed. The amount of preparation necessary depends on types of vegetation and ruggedness of terrain. Roads are aligned in straight lines regardless of gradient or terrain. Trails may have to be cut through forested areas. These operations may result in various disruptions of the environment, including disturbance of vegetation and ground surface, blasting and other noise, and increased presence of humans and vehicles associated with the exploration activity, or local residents taking advantage of the increased access.

2. Portable operations transported by helicopter. Employees and equipment are flown in from staging areas. Explosives are detonated in shallow holes on the surface of the ground or on stakes or platforms. Vegetation and surface disturbance are reduced because road construction is not required. Nevertheless, helicopter activity will result in increased noise.

The degree of impact of seismic activity depends on its intensity—the number of concurrent programs, the number and spacing of lines, and the length of time spent in critical habitats. Two aspects must be considered: the immediate effect of the actual exploration activity, and the subsequent effects resulting from increased access (Stubbs and Markham 1979).

Certain characteristics specific to seismic operations may intensify effects on wildlife. Crews are constantly moving and follow a course unpredictable to wildlife. The activity may cover a large area, and is not confined to one site as is characteristic of drilling operations. Blasting noise is sudden and unpredictable, and its effect may extend beyond the area of immediate surface disturbance and activity. Exploration activities may be especially disruptive if poorly planned and subcontracted to small companies with restricted budgets. Such firms may be less concerned than large oil companies with public relations and therefore more likely to take environmentally destructive shortcuts (Klein 1973).

Exploratory Drilling

In cases where preliminary explorations still indicate the possible occurrence of oil, drilling of an exploratory or "wildcat" well may be initiated to determine if oil and/or gas of commercial quantity and quality exist. Drilling does not begin until a lease has been acquired by the operator. Well depth depends on the geology of the area. Wells in the Overthrust Belt are commonly drilled to depths up to 18,000 ft (Overthrust Industrial Association 1981b), and completion may take 6 months. In other areas, shallower wells of a few thousand feet are common and may be completed in a few weeks.

The steps undertaken in exploratory drilling operations are:

1. **Construction of temporary access roads able to accommodate continuous traffic of large, heavy trucks hauling the drill rig and other materials and equipment to and from the drill site.**—Factors such as time of year, terrain, and duration of drilling activity may influence road construction requirements. Standard road construction practices are followed. Heavy earth-moving equipment is used to clear vegetation for a 10- to 18-ft wide running surface, grade the road surface, cut and fill slopes, cut ditches and borrow pits, transport material used to crown the running surface, install culverts, etc.

2. **Preparation of well site.**—This requires clearing and leveling an area of 1 to 7 acres (10 acres for deep wells) for the drill pad (Kline 1981). This pad holds the drilling rig, mud pumps, mud pits, generators, pipe rack, and tool house. Construction requires stripping of topsoil; cutting, filling, and grading to construct a flat drilling pad; and excavating and banking mud pits to hold drilling mud, cuttings, and waste fluids. The rig is erected and other equipment is hauled in and stored on the pad awaiting use.

3. **Provision of adequate water supply (50,000 to 100,000 gal/day).**—Water may be trucked to the site, or transported by a surface pipeline laid to a water source nearby.

Some seismic exploration for petroleum deposits is conducted using helicopter access rather than trucks, with different types of wildlife effects.

4. **Drilling.**—The actual drilling operation normally uses a rotary drill bit and drill string, consisting of long lengths of pipe, which are rotated and gradually bore into the earth. Additional strings of pipe, or casing, are cemented inside the hole, primarily for safety reasons. Drilling mud, generally a mixture of water, clay, and chemical additives, is forced under pressure down the drill pipe to cool and clean the bit and carry cuttings to the surface. Large, loud, diesel power plants are often required for power at the drilling site (Longley and others 1978).

Various tests, such as "logging," measure the physical characteristics of the rock formations and associated fluids. The well will be completed if sufficient quantities of oil and/or gas are indicated. Completion requires installation and cementing of casing to the bottom of the hole. If no oil or gas is encountered, the well is usually abandoned. If the well is a producer, the area is developed.

Exploratory drilling tends to be much more disruptive to the environment than are seismic operations. This is primarily due to the increased access and need for construction, and the consequent increase in human activity, noise from vehicles and machinery, and disturbance of vegetation and ground surface.

Crews work around the clock (three shifts of five to eight workers) and service traffic may be continuous. Although much of this activity is concentrated in the area of the drill pad and roads, noise associated with construction machinery, heavy trucks, and drilling may be persistent and extend beyond the area of immediate activity. In addition, construction of new roads may open up, temporarily or permanently, previously inaccessible areas for recreation by local residents and workers. The degree of surface disturbance required for the drill pad, mud pits, and road construction may vary according to such factors as well depth, rig size, mud system efficiency, and terrain. For instance, in the Overthrust Belt, the combination of rough terrain and deep wells commonly results in larger disturbed areas. Toxic substances (fuel, crude oil, chemicals) may be released from accidents or leaks (Longley and others 1978). Site-specific disruptions resulting from a well may last only a few months; however, an exploratory program for an area may include many wells and may last for years.

Development and Production

Because the two phases often occur simultaneously and result in similar environmental disruptions, development and production will be discussed together. If a wildcat well becomes a "discovery well" (a well that yields oil or gas in commercial quantities), development begins. Subsequent wells are drilled to establish the reservoir's limits and to facilitate planning the best pattern of wells to drain the field. The drilling procedure is the same as that followed for exploratory wells. As development wells are drilled, they may be tested and temporarily shut in until means of transporting the oil and/or gas is arranged.

Oil field production begins when the oil or gas can be transported by pipeline or truck. This usually occurs soon after completion of the discovery well and is often concurrent with development operations. Temporary facilities are gradually replaced by permanent ones. Often, the majority of surface disturbances occur in this phase, as new wells are drilled periodically throughout the field and pipelines and operational facilities must be built. The extent of surface facilities is determined by reserve size, reservoir characteristics, the mixture of fluids being produced, transportation strategies, availability of existing infrastructure, and whether or not the field is unitized.[1] Such facilities may consist of any or all of the following:

1. **Drill sites.**—Drilling may continue throughout the producing life of the field. Facilities needed are the same as for exploratory drilling.

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[1] Unitization refers to the joining of numerous leases into "unitized" fields which are developed and operated as a unit, upon agreement by developers, without regard for separate ownership.

Oil field development and oil transporation and storage facilities can affect considerable area.

2. **Well heads.**—If formation pressure is sufficient to force the oil to the surface, the well is completed as a free-flowing well and simply closed off using a "Christmas tree," an assembly of valves and pressure regulators used to control the flow of the well. Wells using artificial lift have simple well-head arrangements of valves.

3. **Pumping equipment.**—If natural pressure is not sufficient to raise the oil, a pumping unit may be needed. Surface pumps are usually powered by internal combustion engines or electric motors, which are generally preferred by operators and make less noise but require a source of electricity.

4. **Storage facilities.**—Storage tanks or tank batteries may be placed at well sites or in central locations to be used as collection and shipping points for oil and gas.

5. **Separating and treating facilities.**—If the oil contains gas and water, they are separated, at facilities usually located at the storage tank batteries, before the oil is stored. Gas may be returned to the reservoir or marketed. If marketed, additional treatment facilities may be needed to upgrade the gas for commercial pipeline transport. Deep drilling often produces hydrogen sulfide, a highly toxic and corrosive "sour" gas. The gas must be "sweetened" at plants located near the center of the field because transporting the gas is dangerous. Several plants may be required in an area; and each may cover 20 to several hundred acres (Kline 1981; O'Gara 1980). Separation of water, which often contains very high salt concentrations, may require tall settling tanks or facilities for chemical or heat treatment.

6. **Salt water disposal systems.**—Reinjection of water into the formation may require additional wells and maintenance roads. In some cases, dry holes or depleted wells are used. Surface exploration or percolation pits are sometimes used for salt water disposal or, where necessary, for skimming of oil not completely separated (Clifton and LaVelle 1978; Conner and others 1976).

7. **Roads.**—The design standard of existing roads will be upgraded if necessary for permanent, all-weather access. This may involve widening, ditching, graveling, crowning, or capping the roadbed and installing culverts. Additional roads will need to be constructed to allow increased access to the wells, to treatment and storage facilities, and for construction and maintenance of pipelines, transmission lines, and communication sites.

8. **Electric transmission lines.**—Lines and rights-of-way may be required from main lines to each well site and tank battery and to the communication and production facility. These range from small lines on simple wood poles in narrow rights-of-way to extra-high-voltage lines on steel structures in corridors. Construction usually involves road construction, clearing of vegetation for a right-of-way of variable width, tower installation, and conductor stringing (Lee and Griffith 1978).

9. **Communication systems.**—Communication lines are usually buried, requiring a construction easement and permanent right-of-way. Communication sites typically include repeater and terminal facilities, electric power source, and an access road to permit year-round servicing. All communication facilities have some type of antenna on top of wooden poles or steel towers, which vary in height up to several hundred feet (USDI 1976b).

10. **Pipelines.**—Numerous pipelines will be required. Oil and gas are transferred within the field from the wells to gathering stations, and between gathering stations and treatment facilities, in flow lines generally 4 to 8 inches in diameter. Flow lines can be on the surface, buried, or elevated.

Larger pipelines of variable diameter and length are needed to transport the oil and gas from gathering stations to refineries. The conventional below-grade construction mode typically used for both oil and natural gas pipelines consists of the following major steps (USDI 1976a; USDI and Fed. Energy Reg. Comm. 1981):

— Construction of access roads between right-of-way and pipe yards, borrow pits, and storage areas.

— Preparation of right-of-way. All vegetation and debris must be cleared and the right-of-way graded as necessary. Blasting may be required for removal of rock. Construction requirements, pipe diameter, and soil condition usually establish the width of the right-of-way.

— Excavation of borrow pits as necessary for gravel.

— Pipe mobilization and stringing. The pipe must be hauled to the right-of-way and placed in assembly position along the ditch centerline, with openings at given intervals.

— Installation. The burial trench is dug and the pipe bent, aligned, welded, coated, and lowered into the ditch by crews using various types of equipment. The trench is backfilled with ditch spoil, creating a berm over the pipeline. The right-of-way is then graded to original contours (except berm) and vegetated.

The pipeline is typically laid by several "spreads" working simultaneously along its route. Other components of the pipeline system must also be constructed as necessary, including block valves, metering stations, maintenance bases, cathodic protection stations, and pump and compressor stations to maintain pipeline pressure. Each of these requires a variable surface area ranging from several hundred square feet to several acres and may require additional access.

11. **Facilities for secondary recovery.**—After years of primary production, the reservoir's natural pressure and oil yield declines. Secondary recovery, involving injection of water (water-flooding), gas, or other liquids, is often initiated to artificially increase reservoir pressure.

A service infrastructure is also developed during this phase. A substantial increase in the local population, or "boom town" development, results from the influx of: (1) a very large labor force (hundreds to thousands) required for oil field development activities, (2) workers' families, (3) personnel of service professions needed to provide for the increased population, and (4) personnel of ancillary industries which may result from oil field development. These people require living accommodations, which may consist of (1) company construction camps in remote areas, (2) housing in local communities, or (3) "squatting" with tents, campers, or trailers (Kline 1981). The population increase may last for varying lengths of time, but tends to be greatest during the development and construction phase as temporary workers are imported. A significant increase in permanent residents is likely. In remote areas with difficult access, aircraft support may be needed. This could require construction of airstrips or helipads.

Development and production may take many years and include many wells and facilities. Once a field has been established, environmental disruptions become extensive, cumulative, often long term, and would occur continually in varying degrees because of the need for recurring human activity.

Wildlife habitat alteration or destruction can be considerable due to the increased surface disturbance and vegetation clearing needed for (1) construction activities and (2) placement of permanent operational facilities, well sites, roads, worker accommodations, etc. Aquatic habitats may be altered as a result of siltation and erosion from culvert placement, stream bottom pipeline crossings, and runoff from dirt roads and construction activities.

The presence of human-associated structures and facilities (buildings, roads, pipelines, transmission lines) will increase. Substantial human intrusion into wildlife habitat will result from (1) activities directly related to oil field operations and (2) secondary activities related to the resultant increases in access and population. Traffic will increase significantly. There will be a greater demand on wildlife and its habitat for recreational purposes. Sociological data indicate that energy-development-related workers have a higher demand for outdoor recreation, especially hunting, fishing, and use of recreational vehicles, and therefore a greater potential for increasing impacts on wildlife, than do resident populations in development areas (Streeter and others 1979). Effects from secondary activities may be greater in the long term than those from development itself.

Deliberate harassment of wildlife may occur in some situations. Also, attraction of scavenger species to construction camps, drill sites, or other concentrations of human activity may be a problem in some areas, especially where food, garbage, and sewage are accessible to the animals.

Varying levels of noise will be generated by construction machinery, heavy trucks and other traffic, blasting, generators, air traffic, and other equipment and operations. Noise may be temporary and site-specific, or long-term, depending on the source. Gas turbines and compressor stations are sources of very high level, long-term noise (Banfield 1971; USDI and Fed. Energy Reg. Comm. 1981).

Accidents causing spills and leaks of toxic or otherwise environmentally damaging substances can be expected, despite precautions taken to prevent them. Liquid spills (fuel, oil, brine, chemicals) occur along pipelines, from mud pit failure, at storage tanks and well heads. In some areas, brine spills are a more serious problem than oil spills. Brine spills may be more frequent than oil spills, and brine is more damaging and less easily recoverable than oil (de Jong 1980; Kennedy 1979).

Reclamation/Abandonment

The operator must submit an abandonment plan and request permission from the U.S. Geological Survey (USGS) to begin abandonment operations. Dry holes and depleted producing wells are plugged with cement. Drilling rigs and support equipment are removed from unsuccessful wells. When an entire lease is abandoned at the end of the production phase, processing, treating, and handling equipment is removed. Surface flow lines are removed, but buried lines are usually plugged and left in place. The surface, including mud pits, must be restored to the requirements of the surface management agency and stipulations of the lease. Earth-moving equipment is used to move disturbed soil back near its original place and to contour the site. Topsoil is replaced and the area is reseeded. Surface rehabilitation may be quite difficult. Access roads may be rehabilitated to previous conditions, abandoned, administratively closed, or left for local residents to use and maintain.

No unique environmental disruptions are likely. Abandonment should result in the removal of most human-associated structures and termination of development-related activity and noise. Wildlife habitat may be restored or improved.

It is possible that disrupted ecosystems may never be totally rehabilitated, as human settlement occurring during development and production may persist. Moreover, impacts will have been cumulative over many years during the life of the oil field.

IMPACTS ON WILDLIFE

This section summarizes the effects on wildlife behavior, habitat, and populations that may result from the environmental disruptions previously described. The report also includes (1) an index of disturbances (appendix A) keyed to (2) an annotated bibliography (appendix B).

The index is organized by major environmental disruptions (headings) and their primary effects (subheadings). Within each subsection, keywords, relating to numbered references, describe such subjects as the species affected, the agent of disruption, the specific response of the wildlife, the significance of the effect, the factors affecting degree of response, and special cases of high sensitivity. The outline is based entirely on the information presented in the literature reviewed; therefore, not all subjects are included in each section. The numbers following the keywords direct the user to the annotations, which discuss the effects in more detail. Annotations summarize only data and conclusions judged pertinent to the subject of this paper, and may not represent complete abstracts of entire publications.

The outline and the bibliography must be used together for full benefit. Such a format presents—in the outline—an overall summary of the effects of each disruption. It simultaneously allows research results to be reported—in the annotations—in greater detail and in their original context. This also avoids repetition of results, as many of the publications reviewed address several types of effects and/or disruptions and are pertinent to several sections.

The outline is also intended for use as an index to quickly direct the reader to those subjects of most interest. These may overlap to some extent—such as noise and aircraft disturbance or noise and traffic. However, distinctions were made because of the unique combination of stimuli included in each effect. For instance, aircraft disturbance includes a specific type of visual stimulus as well as a noise component. Traffic activities may include noise and visual stimuli but are distinct because they occur along a fixed corridor.

To facilitate organization, 10 primary effects are distinguished. Papers describing neutral or positive effects on wildlife are also listed. The paper concentrates on primary effects that result directly from a disruption. The significance of the effects is noted when addressed in the literature. For instance, the presence of human-associated structures (disruption) may interfere with movement (primary effect), which, if severe or prolonged, may then result in reduced reproductive success or loss of available habitat (significance). Increased human/wildlife encounters (disruption) may cause animals to avoid an area (primary effect), which, over time, might result in changes in distribution, or alteration of activity patterns or movements (significance). Table 3 summarizes the primary impacts resulting from each environmental disruption. Table 4 shows the significance of primary effects.

This report presents a "worst case" scenario of potential effects. Strategies exist that allow some of these effects to be minimized. Moreover, the severity of an effect is site-specific and depends on such factors as the sensitivity of the species involved, the nature of the disruption, characteristics and importance of the affected habitat, and the availability and condition of alternative habitat (Hanley and others 1980; Streeter and others 1979; USDA 1981b).

Table 3.—Primary impacts potentially resulting from environmental disruptions

	Environmental disruption						
Primary impact	Noise	Aircraft	Human intrusion	Traffic and access	Structures and facilities	Alteration of vegetation/ land	Harmful substances
Interruption of activity/ alarm/flight	x	x	x	x			
Avoidance/displacement	x	x	x	x	x		
Permanent loss of habitat use			x	x		x	x
Decreased reproductive success		x	x				
Interference with movement	x	x	x	x	x		
Direct mortality			x	x	x		x
Interference with courtship	x		x				
Alteration of behavior			x				
Change in community structure						x	

Table 4.—Secondary impacts which may occur as consequences of primary impacts

	Primary impacts									
Secondary impact	Interruption of activity/alarm/ flight	Avoidance / displacement	Permanent loss of habitat	Decreased reproductive success	Interference with movement	Direct mortality	Nest/den abandonment	Interference with courtship	Change in community structure	Alteration of behavior
Decreased use/temporary desertion of traditional areas		x								
Shift in range		x								
Change in distribution		x								
Overutilization/over-population of adjacent habitat		x	x							
Use of marginal habitat		x								
Gradual range abandonment		x			x					
Inefficient use of habitat	x	x	x		x					
Mortality		x						x		
Reduced feeding efficiency	x	x								
Change in activity patterns	x	x								
Interference with/alteration of movements		x								
Decreased availability/ elimination of food source			x			x				
Inadequate nutrition					x					
Insufficient energy reserves for migration					x					
Reduction in numbers			x							
Adverse physiological effects			x		x					
Disruption of social structure/group composition		x			x					
Reduced reproductive potential/success	x		x		x					
Nest desertion		x								
Decrease in nest density/ sites			x							
Delay/failure to den					x					
Den displacement		x								
Decreased survival/loss of young			x		x					
Increased use of alternate nests		x								
Decrease in aquatic productivity			x							
Human injury/property damage										x
Delay/failure to reach traditional range					x					
Ease of travel					x					
Increased vulnerability to predators					x					
Interference with mating synchrony					x					

ENERGETICS OF DISTURBANCE: IMPLICATIONS FOR ANIMAL PHYSIOLOGY

Environmental disruptions may have an additional subtle but important effect on wildlife often overlooked by resource managers. Any changes in an animal's "normal" routine will have some effect on the energy and nutrient budgets of the individual. Energy budgets describe the partitioning of energy flow in the animal body (Hudson and Stelfox 1976). The bioenergetic approach to animal-habitat relationships assumes that "undisturbed animals should exhibit patterns of activity and habitat selection that result in optimization of energy budget" (Morganini and Hudson 1979). Each species possesses strategies to maximize homeostasis and efficiency of nutrient uptake and use, so that a maximum amount of energy is spared from maintenance for reproduction (Geist 1978). Energy expenditure is related to the level of daily activity in addition to maintenance of homeothermy. Deviations from normal activity patterns and habitat use may have profound effects on the energy budget and, therefore, the welfare and productivity of an animal (Burton and Hudson 1978). Negative effects of environmental disruptions (flight, avoidance, interference with movement) raise the energy cost of living at the expense of energy needed for reproduction and growth (Geist 1970). This increased cost results from:

1. The cost of physiological excitement preparing the animal for exertion. This reaction may not be detectable

because the animal "may rigidly control its skeletal muscles while its organ system remains prepared for instant exertion" (Geist 1978). Frequent preparation for flight imposes a burden on the energy budget. Increases in heart rate have been shown to precede or occur in the absence of overt behavioral reactions (MacArthur and others 1979). Geist (1978) states that excitement generally raises an animal's metabolism by about 25 percent above that required for maintenance.

2. The cost of locomotion incurred when an animal attempts to escape a disruption, is forced to deviate from traditional migration routes, etc. This cost varies with such factors as speed, distance, and terrain (Geist 1978). According to Burton and Hudson (1978), flight is the most energetically expensive activity. Geist (1971) calculated a 21 percent increase in cost of living for a caribou, chased by aircraft, which ran for 10 minutes, walked 1 hour, and remained excited for 1 hour more. He determined this expenditure was 3 percent more than the animal's total possible forage consumption. The additional cost must then be drawn from energy stores at the expense of reproduction and growth. The costs of locomotion and excitation are very high compared to normal food intake and energy expenditures (Geist 1978).

3. The cost of lost food intake. An animal responding to a disruption is not able to eat; feeding time is therefore lost. In addition, feeding behavior is dependent on emotional status. Food intake decreases when an animal is disturbed (Hudson and Stelfox 1976).

4. The cost of suboptimal habitat selection. Avoidance of a disruption, interference with movement, and vegetation alteration or destruction may prevent animals from (1) selecting habitats to compensate for adverse climatic conditions, and (2) feeding in preferred areas, where forage is of higher quality or greater availability. The latter may contribute to the decrease in food intake. Low quality forage is digested slowly and therefore cannot be consumed in quantity (Hudson and Stelfox 1976). White and others (1975) found that forage digestibility was an important determinant of the amount of food retained as fat in caribou and reindeer.

If an animal is unable to compensate for such increases in its cost of living, reproduction, growth, and survival may be adversely affected (Geist 1970; Owens 1977). Geist (1979 as cited in Johnson and Lockman) believes that animals can expend relatively little "spare energy" in summer without running an energy deficit. Increased energy costs are most detrimental—for ungulates in particular—during critical times of the year when the animals are already in a state of negative energy balance, e.g., cold weather, late pregnancy, and fly season (especially in northern regions) (Geist 1971 and 1978). During these periods, the energy deficit is increased through the negative effects of disruptions. Increased calf mortality, delayed maturity and smaller body size of adults, reduced survival in winter due to insufficient fat reserves, and decreased reproductive performance may result (Geist 1979 as cited in Johnson and Lockman; Moen 1978). The demands of reproduction are fixed in time (highest in late winter, early spring) and must be met, or productivity is reduced. White-tailed deer produce smaller fawns in late spring when a lack of nutritional forage creates a negative energy balance (Moen 1978). Deer are able to conserve substantial amounts of energy in winter by decreasing their activity. Increasing physical and physiological activity in response to environmental disruptions, however, negates the advantages of this adaptation (Moen 1976). White and others (1975) found that harassment by insects can substantially raise the maintenance energy requirements of caribou by increasing the amount of time the animals spend standing and moving, and reducing feeding and resting time. Additional energy costs at this time may cause disease or even death (Geist 1971).

Ungulates, such as these mule deer fleeing from a helicopter, are one of the major wildlife groups affected by petroleum activities, and are stressed in this review.

The ability of both wild and domesticated reindeer to adapt to changes in their environment and to adjust to disturbances is evidently influenced by the animal's physical condition. Migrations are easily disrupted, and traditional ranges abandoned, when the reindeer are in poor physical shape (Klein 1971). It therefore seems possible that the negative effects of environmental disruptions, by creating an energy deficit that adversely affects an animal's physical condition, may reduce the individual's ability to respond to subsequent disruptions, thereby potentially causing greater energy deficits and accelerating the negative consequences.

MITIGATION

Mitigation[2] may be defined as "a class of actions which have the purpose of counteracting the effects of disruptions on the natural environment and on renewable resources, associated with new physical structures and/or construction activities, and/or management objectives and practices" (Jahn 1979). It refers to "management to reduce, abate, or alleviate an adverse impact." It generally does not refer to complete prevention of impacts, but rather implies that some losses will occur. The goal is to make that loss less severe (Thompson 1979). This section discusses planning for mitigation and describes general approaches for minimizing the adverse impacts of petroleum exploration and development on wildlife including (1) project management, (2) wildlife management, and (3) personnel management.

Planning

The following points should be considered in planning for mitigation:

1. Mitigation is more likely to be implemented when it is an integral part of the original planning process. Wildlife needs and objectives should be considered at the earliest planning stage, i.e., when leasing decisions are made (McGowan 1978; Short and Schamberger 1979; Streeter and others 1979). The sequence of leasing may determine future effects on wildlife. Wildlife biologists may influence this by (1) recommending at this early stage a preferred sequence of development, based on biological values and priorities, which ranks the suitability of lands for development, and (2) by providing alternative leasing possibilities and "trade-off plans" for sensitive areas selected for development. Appropriate mitigation measures may then be incorporated into the initial project design. This strategy may be more effective and manageable than responding to each permit after lease decisions have been made (McGowan 1978; Pamplin 1979; Streeter and others 1979).

2. "An accurate, timely, well-formulated, and complete description of biological resources and their responses to disturbance provides the basis for informed decisions regarding those resources" (Hanley and others 1980). Implementation of baseline studies and development of a comprehensive biotic resource data base describing predevelopment environmental conditions will provide a basis for (1) deciding whether, where, and how to develop, (2) identifying sensitive wildlife and habitats, (3) predicting effects, (4) developing mitigation and monitoring programs, and (5) gaining insights into effects through postdevelopment comparison (Deitz 1979; Hanley and others 1980). The ability to demonstrate the presence of critical wildlife populations or habitats and their sensitivities to potential disruptions will strengthen the wildlife manager's position in the decision-making process and help ensure protection for wildlife. At the early stages of planning for development, resource managers should identify the likely range of wildlife issues, determine what information is needed, and establish tentative priorities for obtaining it. The following points should be considered when making decisions regarding information requirements (Hanley and others 1980).[3]

— Acquire as complete a resource information base as conditions allow.

— Choices must be made about the information that has highest priority, and decisions made about the minimum level of information that allows an accurate and satisfactory estimation of impacts.

— The ultimate goal is to minimize negative effects on wildlife; therefore, emphasis should center on acquisition of information that will help decision makers achieve this goal.

— The detail of information available for a particular site may affect the resource management philosophy applied to the site.

— Information needed for decisions must be available at the right time.

— Information needs tend to become more specific and detailed as the decision process progresses from early to late phases.

— Identification of ecologically sensitive and/or valuable areas is a primary information need during all phases of development.

— Time and money spent on information collection and dissemination should reflect the potential for, and severity of, effects of a proposed activity.

3. Wildlife managers should participate in, and influence, the establishment of stipulations—that is, procedural, environmental, and technical requirements to be met by developers in all phases of activity—to ensure maximum protection of wildlife. These should be based on an evaluation of potential effects and should be included in the lease or right-of-way agreement (Hanley and others 1980; McGowan 1978; Streeter and others 1979). Stipulations may include (1) no surface occupancy on selected areas, (2) restrictions on the season of operation, (3) special reclamation requirements, (4) restrictions on the rate of development and location of wells and facilities, (5) road closure requirements (USDA 1981a), and numerous other measures as necessary. Standard stipulations developed by the land management agency are generally supplemented by special stipulations specific to a project.[4]

4. Provision of a plan to monitor—in the field—development activities, effects on wildlife, and mitigation efforts should be considered essential, and may be included in the lease agreement (Dietz 1979; Pamplin 1979; USDA 1981b). The goals of a monitoring program, as stated by U.S. Department of the Interior (1981b) are as follows:

— To determine if the impact predictions are accurate.

— To discover unanticipated and/or unpredictable impacts.

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[2] A very comprehensive treatment of the subject, including discussions on techniques, planning, problems, evaluation and inventory of habitats and impacts, etc., for many forms of development is available in Swanson (1979).

[3] A very comprehensive discussion of "information needs for natural resource protection during petroleum development" is available in Hanley and others (1980), which can be obtained from the Office of Biological Services, U.S. Fish and Wildlife Services, 1011 E. Tudor Rd., Anchorage, AK 99507.

[4] Consult completed environmental impact statements and Hanley and others (1980) for specific examples of stipulations.

— To determine if mitigation measures are working as prescribed.

— To determine if the action is fulfilling the purpose and need for which it was developed.

— To assist in resolving differences of opinion concerning impacts.

— To assure that decisions are being implemented.

Provisions should be made during the planning stage to allow for modification of ongoing mitigation activities if judged necessary as a result of the monitoring program (Jahn 1979). A unique, interagency surveillance/monitoring system—the Joint Fish and Wildlife Advisory Team (JFWAT)—was organized to provide for the protection of fish and wildlife resources during construction of the Trans-Alaska Pipeline. The team consisted of State and Federal biologists working jointly to ensure compliance with environmental stipulations, address fish and wildlife-related problems developed during the course of development, and offer advice on how best to protect these resources (Kavanagh 1977; Klein 1979; Morehouse and others 1978; Pamplin 1979).[5]

Approaches for Minimizing Negative Effects on Wildlife

PROJECT MANAGEMENT

(Sources: Banfield 1971; Barry and Spencer 1976; Calef and others 1976; Interstate Oil Compact Comm. 1974; Lyon 1975; Miller and Gunn 1980; Pedersen 1978; Stalmaster and Newman 1978; Streeter and others 1979; Stubbs and Markham 1979; Thompson 1979; USDA 1981b; USDI 1976a, 1981a, 1981b; USDI and Fed. Energy Comm. 1981; Ward 1973.)

The development project can be managed by any or all of the following means to minimize negative effects on wildlife. A local data base identifying sensitive species, habitats, and times of year will be necessary for defining restrictions on development.

1. Spatial management

— Avoidance by development activities, roads, facilities, and structures, of locations which are sensitive and/or critical to wildlife, for example, ungulate winter ranges, breeding areas, raptor nests, waterfowl molting and staging areas, critical habitat of endangered species.

— Use of buffer zones or screens to reduce wildlife visual contact with roads and development activity. Buffers may include topographic barriers, vegetation, and/or distance, and are especially recommended for elk and raptors.

— Provision of security areas, especially for ungulates, which contain necessary habitat elements and are sheltered from disturbance. This may be accomplished by restricting roaded activities to one out of two adjacent drainages at any one time. Ridgelines should not be developed in any way.

— Maintenance of security cover in wildlife travel lanes.

— Restriction of aircraft activity to defined flight paths which avoid sensitive areas.

2. Temporal management

— Restriction of activities to seasons and/or times of noncritical wildlife use. Managers should compile a list of dates when development activities should be prohibited in certain locations due to specific needs, such as breeding, calving, migration or local movements, molting (waterfowl), etc.

3. Operational management

— Employment of techniques and methods of development which may reduce negative effects on wildlife. Examples include:

- — Reductions of surface use requirements and facility duplication by joining numerous leases into a unitized field.
- — Coordination of proposed activities to control the number of roads, rights-of-way, etc. Rights-of-way can accommodate several pipelines and/or powerlines to minimize habitat destruction.
- — Use of helicoptor support, where possible, in sensitive areas.
- — Control of aircraft altitude, scheduling, and activities. Following and circling wildlife should be prohibited.
- — Closure of oil field access to unauthorized traffic, and permanent closure and rehabilitation of roads no longer needed.
- — Regulation of oil field traffic to control speeds, numbers of vehicles using the road, and/or timing of use.
- — Design of fences, pipelines, and aboveground structures, and construction of highway underpasses (Reed and others 1975) to minimize interference with wildlife movements.
- — Burial of utility lines in areas with high collision risk for birds.
- — Seeding of roadsides with plant species unpalatable to wildlife and planting "feed plots" away from the road to reduce wildlife-vehicle collisions and poaching.
- — Insulation of noise sources, especially compressor station.
- — Covering, fencing and/or elimination, and eventual rehabilitation, of oil field sump pits.

WILDLIFE MANAGEMENT

The behavior of mammals is influenced by their ability to learn. Teaching animals, by using the principles of learning behavior, can be a management tool used to assist wildlife in adjusting to change resulting from human activity (Geist 1978). Habituation to humans allows wildlife to efficiently use habitat near human activity, without expending large amounts of energy in physiological stress and fear responses (Tracy 1977). According to Geist (1978), animals have the ability to habituate to humans, and are only as wild as we teach them to be.

An animal functions best in a familiar, predictable environment. It learns to respond in definite ways to given stimuli to reduce uncertainty and indecision, and to make adjustments (for example, flight) to achieve a familiar environment. It will initially react to an unfamiliar stimulus with a combination of fear and curiosity. The animal's subsequent reactions to the stimulus depend on the experiences associated with it (Geist 1978; Tracy 1977). Geist (1970) states that a wild ungulate's behavior toward humans is largely a consequence of our behavior toward the animal. If an encounter with humans is followed by an alarming event, such as pursuit, the animal will respond to subsequent similar encounters with alarm, flight, and avoidance. If the initial alarm response is not reinforced during the first encounters, habituation will occur. If the animal is rewarded, it will become attracted to humans. An animal may generalize to stimuli which it perceives as similar. Large mammals that are hunted cannot be expected to habituate to hikers, as they will generalize from hunters to other humans (Geist 1978; Tracy 1977). Wildlife will become habituated to predictable events that are not followed by painful and/or harmful events (Geist 1971).

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[5] These references provide further descriptions of JFWAT's organization and operation and give recommendations for the formation of future teams. Hanley and others (1980) also discuss surveillance programs.

Habituation ability varies among wildlife species and is influenced by the species' learning ability, perceptive abilities, and sensitivity threshold, and by the type of stimulus (Geist 1978; Tracy 1977). Geist lists three types of harassing stimuli for ungulates: (1) those that are not familiar or predictable, (2) those involving sharp contrasts or sudden changes in the environment, for example, quick movements, sudden loud noises, and (3) those to which an animal responds innately with alarm. The latter are generally used to identify dangers present throughout the species' evolution—predators and natural environmental hazards—and are not easily modified by learning (Bergerud 1974). A direct, close approach may produce such evolutionarily based fear responses in a number of species, as it is generally associated with predators (Tracy 1977).

Habituation by wildlife to human activities can be encouraged by (1) avoiding or minimizing fear-provoking stimuli—direct approaches, stalking, loud noises, quick movements, etc.—during human-wildlife encounters, (2) controlling the timing, frequency, and intensity of human activities to make them more regular, and therefore more predictable, and (3) minimizing the frequency and intensity of human-wildlife encounters during times when wildlife are particularly sensitive to disturbance (Tracy 1977).

Habituation may be an advantage to wildlife in many situations, as it allows animals to more efficiently use habitat near human activity. However, in some cases, habituation could be potentially detrimental to wildlife. In particular, animals that adapt to human activity along roads may be more susceptible to poaching, hunting, and collisions with vehicles. Data show that elk habituated to a highway in Glacier National Park and furbearers waiting for "handouts" along the Alaska pipeline haul road have been vulnerable to poaching (Milke 1977; Singer 1975). The feasibility and desirability of encouraging habituation will vary with the situation. Future land use plans and objectives—especially with regard to access—and the ability to control human activity such as hunting, poaching, and use of roads should be considered. The potential benefits and harm to wildlife resulting from habituation should be evaluated for each project. Knowledge of local wildlife populations and their behavior and an understanding of habituation are critical to decisions concerning the compatibility of petroleum development and wildlife.

The large aboveground Alaska pipeline may affect some animal movements, but these grizzly bears moved beneath it.

PERSONNEL MANAGEMENT

(Sources: Streeter and others 1979; Stubbs and Markham 1979; USDA 1981b; USDI 1976a; USDI and Fed. Energy Reg. Comm. 1981).

The negative effects of petroleum development on wildlife can be further reduced by regulating the activities of oil field workers to minimize interactions with wildlife.

The following methods are suggested:

— Company provision of housing and/or camping areas in locations that avoid sensitive wildlife areas (elk meadows and desert bighorn and quail water sources), and restrictions on "squatting" in such critical areas.

— Busing of employees from living quarters to the work site. This has been shown to significantly reduce the incidence of poaching (Streeter and others 1979).

— No firearms on the project site and in vehicles using oil field access roads.

— No recreational off-road vehicles on oil field access roads.

— Specifications for garbage and food handling and disposal to prevent wildlife attraction.

— No feeding of animals.

Regulations must be backed by cooperative enforcement, effective penalties, and a firm commitment by management (USDI 1976a; USGS 1979). In addition, petroleum companies may be required to provide environmental education programs for all personnel, including truck drivers (USDI 1976a). Such a program might discuss: (1) basic concepts of ecology and animal behavior, (2) rules, regulations, and suggestions for minimizing the effects of human activity on the environment, (3) the biotic resources found in the area, and (4) the ethics and responsibilities involved in outdoor recreation. The Overthrust Industrial Association[6] (1981c) is planning an Environmental Awareness Training Program.

CONCLUSIONS

Research on the potential effects of human activities on wildlife has concentrated primarily on documenting observable, behavioral responses of wildlife to human-caused disturbance. Many results are conflicting. Few studies have conclusively demonstrated the effects of human activities on the survival or productivity of wildlife populations. This may not be easily shown due to the number of factors involved (Jingfors and Gunn 1981), the lack of environmental control, and the difficulties in devising appropriate methodology. Moreover, it is often difficult to separate natural variations in population from human-caused variations without baseline, predisturbance data (Hanley and others 1980). Such data have not been available for many studies, which were initiated in response to environmental disruptions from ongoing activities. Efforts should be made to gather baseline data which will allow more definitive conclusions from future studies, based on long-term comparisons of predisturbance and postdisturbance data. Until such results are available, wildlife managers will have to rely on behavioral observations and generalizations if they are to minimize the negative effects of current development. The following conclusions may be drawn from the literature currently available:

1. The potential effects of petroleum development on wildlife in wildland environments are numerous and varied.
2. The severity of the effect is site-specific and depends on such factors as (a) the sensitivity of the species affected, (b) the nature of the disruption, (c) the characteristics and importance of the affected habitat, and (d) the availability and condition of alternative habitat.
3. The major wildlife groups affected, as reflected by emphasis in the literature, are ungulates, carnivores, water birds, upland birds, and raptors. Small birds and mammals may be affected in large numbers, but generally only locally. They are more capable of rapid recovery because of their high reproductive rate and wide distribution.
4. Response to disruptions varies among species and/or individuals and is dependent on numerous factors including: (a) the previous experience of the animal with a given disruption, (b) characteristics of the disruption, (c) characteristics of the habitat, (d) characteristics of the animal and/or group, and (e) timing of the disruption in relation to critical periods of the animal's life cycle.
5. The effects of petroleum development may be most critical in certain highly sensitive situations including: (a) during times when animals are already stressed by natural conditions, (b) in habitats traditionally used by populations during critical periods of their life cycle, (c) for species whose social organization and/or behavior makes them particularly susceptible to disturbance, and (d) for certain sex/age groups of animals.
6. An understanding of general concepts of animal behavior and energetics is necessary to fully comprehend the consequences of petroleum development activities on wildlife.
7. Negative effects can be minimized by numerous means, including project, wildlife, and personnel management.

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APPENDIX A: BIBLIOGRAPHIC INDEX

Numbers refer to entries in annotated bibliography.

Noise

1. **Interrupted Activity/Flight**

Species affected

general 14
big game 38
Dall sheep 100, 104
mountain goats 90
moose 100
caribou 100
waterbirds 13
brant 81
bald eagle 94

Agent of disruption

tourists 100
gunshots 81, 94
supersonic jet 13
vehicles 90
blasting 104

Highly sensitive situations

initial exposure to sound 14, 38, 90
sudden loud noise 14, 81, 90, 94, 100

Factors influencing magnitude of effect

experience associated by animal with sound 38, 90, 100
proximity of sound 81
intensity of noise 13
biological state of animal 14

2. **Avoidance/Displacement**
(refer also to table 5)

Species affected

general 14, 22, 42, 46, 102
big game 38
caribou 103, 104
elk 58, 111
Dall sheep 103
moose 70
reindeer 33, 98
lambs 2
waterfowl 103, 104
snow goose 10
falcons 104

Agent of disruption

drilling 58
traffic 111
sonic booms 22, 33
blasting 104
compressor station simulation 10, 103

Table 5.—Maximum land areas avoided by wildlife due to noise of pipeline surveillance aircraft flying at 500 ft (table 3.1.1. 15—5 in reference 103)

Wildlife	Season or activity	Estimated total pipeline miles[1]	Estimated maximum area (mi^2) avoided by wildlife
Caribou	Calving	58	19
	Postcalving aggregation	38	12
	May/June	90	30
	July/August	58	19
Sheep	Summer range	13	26
Moose	—	8	1
Grizzly bears	—	99	32
Snow geese	Premigratory staging grounds	77	770

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[1] Data supplied by Northern Engineering Services Co., Ltd.

Significance

decreased use of traditional areas 10, 42, 58, 102, 103, 111
nest desertion 104

Factors influencing magnitude of effect

experience associated by animal with sound 14, 38, 46, 58, 104
unexpected sounds 14, 81
regularity/frequency of noise 2, 14, 22, 33, 38, 58, 81, 98, 104
sound localization/extent of influence 38, 58, 102
intensity of noise 2, 102, 111
proximity of sound 104
combination of sound with visual stimulus 14, 70, 98
biological state of animal 14, 33, 98
activity of animal 33
season 103

Highly sensitive situations

initial exposure to noise 14, 22
sudden loud noise 14, 98
staging geese 10
winter 98
calving 98
female/young 100, 104
breeding 14, 33
colonial nesters 22

3. Interference with Movement

Species affected

caribou 103
snow geese 10, 103

Highly sensitive situations

staging geese 10, 103

Agent of disruption

compressor station simulation 10, 103

Specific effect

deflection of movement 10, 103

Significance

insufficient energy reserves for migration 10, 103

4. Interference with Courtship

Species affected

general 72
prairie chicken 107

Agent of disruption

oil field operations 107

Specific effect

masking of courtship signals 72, 107

5. Neutral/Positive Effects

Species affected

general 14, 22, 38, 102
moose 70
reindeer 33, 98
caribou 104
Dall sheep 104
mountain goat 90
elk 111
lambs 2
bald eagle 94
geese 81
falcons 104
wild turkey 66

Agent of disruption

tourists 90
trains 90
industrial activity 38
sonic boom 33, 66
blasting 104
shooting 81
airport 14, 38
traffic 70, 111
construction 104

Aspect

behavioral reaction to noise - all references
use of noisy areas 14, 38, 102, 104
productivity 66

Aircraft Disturbance

1. Interrupted Activity/Flight

Species affected

Dall sheep 103
musk-ox 76, 77
pronghorn 65
caribou 6, 15, 41, 56, 76, 103
moose 56, 103
reindeer 98
grizzly bear 44, 56, 87, 103
wolf 103
shorebirds, waterfowl 7, 13, 120
snow goose 10, 105
Canada goose 103
brant 81, 89
common eider 103
raptors 103

Agent of disruption

helicopter 6, 7, 15, 41, 44, 56, 65, 76, 77, 81, 87, 89, 103, 120
fixed-wing aircraft 6, 15, 44, 56, 81, 89, 103

Factors influencing magnitude of effect

animal's previous experience with disruption 44, 56, 65, 77, 87
aircraft altitude 7, 10 15, 56, 65, 76, 81, 103, 105
aircraft distance 65, 76, 81, 103
aircraft flight characteristics 15, 76, 77, 81, 103
noise 65, 81
type of aircraft 6, 10, 15, 44, 56, 81, 87
animal's experience with being hunted, captured from aircraft 44, 87, 103
timing of overflights 76, 77, 89
season 15, 56, 103
degree of insect harassment 15, 56
rutting activity 77
recent exposure to wolf attack 77
activity of animal 15, 56, 76, 103
presence of calves 76
size of group 15, 56, 76, 103
separation of cow and calf 41
terrain 76, 103

Highly sensitive situations
incubating birds 103
staging geese 10, 105
calves 15, 41
female/young 15, 41, 56, 76, 103
molting waterfowl 89
winter 15, 103
calving 15
rut 15
insect season 15, 56
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landing/combination with human disturbance 76, 77
low altitude flights 7, 56, 65, 77, 81, 105
circling/following 15, 76, 77, 103
helicopters 6, 7, 15, 44, 56, 81, 87, 103

2. **Avoidance/Displacement**
(refer also to table 5)

Species affected
musk-ox 103
Dall sheep 103

Agent of disruption
helicopter 103

Significance
decreased use of traditional area 103
temporary desertion of area 103
shift in summer range 103

3. **Decrease in Reproductive Success**

Species affected
shorebirds, waterfowl 7, 103
brant 103
bald eagle 103
grizzly bear 87

Factors influencing magnitude of effect
combination with on-the-ground human disturbance 103

Agent of disruption
helicopter 7, 87, 103
nest survey 103

Specific effect
lower nest success 103
decreased production of young 103
loss of eggs 7, 103
nest abandonment 103
den abandonment 87

4. **Interference with Movement**

Species affected
caribou 6

Agent of disruption
jet-copters 6

Specific effect
alter direction of travel 6

5. **Neutral/Positive Effect**

Species affected
musk-ox 76, 77, 103
deer 65
moose 56
caribou 6, 15
wolf 56, 71, 103
waterbirds 13, 103, 120
wading birds 60
brant 89
oldsquaw 120

Factors influencing magnitude of effect
frequency of exposure/airfield nearby 65, 103, 120
animal's previous experience with disruption 56, 71, 76, 77, 103
aircraft altitude 6
type of aircraft 6
timing of overflights 76, 77
season 15
lack of negative associations by animal 71, 103

Agent of disruption
float plane 103
helicopter 6, 15, 60, 65, 76, 77, 120
fixed-wing aircraft 6, 60, 71, 103

Aspect
behavioral reaction to aircraft - all references
nest density 120
herd splintering 76, 77
range abandonment 76, 77
abandonment of calves 15

Increase in Human/Wildlife Encounters

This section considers the increasing wildlife-human encounters, both direct and indirect, resulting from the greater human demand on wildlife habitat that accompanies oil field exploration and development. It includes (1) activities directly associated with specific development operations and facilities (generally localized and predictable) and (2) secondary activities related to increases in population and access resulting from oil field development (generally widespread, less predictable, and permanent). Traffic and road-related activities are discussed separately.

1. **Interrupted Activity/Flight**

Species affected
bighorn sheep 48, 59, 64, 114
elk 1, 88, 90
deer 9, 11, 84
moose 1, 70
caribou 25
mountain goat 90
brown bear 100
wolf 19, 71
waterbirds 13
common loon 99
brant 81
bald eagle 94
osprey 3

Significance
reduced nest success 3, 99
reduced feeding efficiency 81

Agent of disruption
recreation 3, 13, 19, 81, 99, 100
approach by human 1, 11, 19, 25, 48, 59, 64, 70, 71, 88, 90, 94, 114
harassment 88
human scent 100
snowmobile 11, 84

Highly sensitive situations
female/young 1, 25, 64
incubation 99
ground nesting birds 3
adult or feeding bald eagles 94

Factors influencing magnitude of effect
animal's previous experience with disruption 1, 9, 19, 70, 90, 94, 99, 100
manner of human approach 1, 48, 59, 64, 70, 84, 88, 99, 114
proximity of activity 13, 19, 25, 48, 94
amount of movement 13
terrain, vegetation 1, 19, 84, 94
animal group size 1, 25, 48
age of animal 94
activity of animal 70
physiological status 1
relation of cover 13, 48, 64, 70, 84

2. **Avoidance/Displacement**

Species affected
large mammals 36
elk 58, 63, 67, 82, 111, 112, 113, 121
deer 26, 30, 50
pronghorn 107
red deer, chamois 8
caribou 16, 57, 120
bighorn sheep 17, 62, 114
large predators 106

- grizzly bear 34, 44
- arctic fox 29
- waterbirds 7, 13, 104
- herons 115
- bald eagle 80, 94

Highly sensitive situations

- female/young 7, 16, 57, 58, 63
- areas of dependable forb production 107
- molting waterfowl 7, 104
- desert bighorn sheep waterholes 17, 62
- nesting birds 115
- adult bald eagles 94

Agent of disruption

- seismic operations 58
- oil field operations 7, 16, 29, 44, 57, 58, 104, 106, 107, 120, 121
- timber harvest 67, 111, 112, 115
- construction 17, 62, 82
- recreation 111, 113, 114
- hunting 8
- snowmobile 26, 30
- cattle drive 50
- harassment 34, 38
- general activity 36, 38, 63

Factors influencing magnitude of effect

- presence of vegetative/topographic screen 16, 67, 111, 112
- intensity of activity 29, 34, 112
- cover 111, 113
- animal's previous experience with disruption 26

Significance

- decreased use of traditional areas - all species references except 30, 50, 58, 80, 94, 114
- change in distribution 8, 26, 57, 62, 67, 94, 112, 115
- overutilization of adjacent habitat 17, 62, 94, 106
- use of marginal habitat 8, 36, 38, 63, 94
- change in activity patterns 17, 34, 36, 114, 120
- alteration of movements 8, 26, 50, 58, 62, 121
- gradual range abandonment 16, 38
- shift of home range 26, 50
- reduced feeding efficiency 34, 58, 62, 94, 107
- increased use of alternate nests 80

3. **Reduction of Available Habitat**

Species affected

- ungulates 35, 38
- bighorn sheep 24, 27 28, 64
- caribou 10, 16
- osprey 96
- deer 69

Factors influencing magnitude of effect

- social behavior of species 24, 35
- intensity/frequency of human use 27, 28, 64, 96

Agent of disruption

- oil field operations 10, 16
- recreation 28, 96
- general human activity 24, 27, 38, 64
- subdivisions 69

Highly sensitive situations

- bighorn sheep 24, 27, 28, 64
- female/young 16
- nesting birds 96
- highly gregarious ungulates 38
- winter range 69

Significance

- reduction in wildlife numbers 10, 24, 27, 28, 38, 69, 96
- overpopulation of adjacent habitat 24, 35
- inefficient use of habitat 35
- adverse physiological effects 24, 35
- decrease in reproductive potential 69

4. **Decrease in Reproductive Success**

Species affected

- ungulates 35
- bighorn sheep 24
- red deer/chamois 8
- caribou 10, 37
- waterfowl 7
- common loon 99
- herons 101
- osprey 3, 96
- ferruginous hawk 116
- upland birds 108

Factors influencing magnitude of effect

- intensity of activity 8, 96, 99
- activity timing in relation to reproductive stage 96, 101
- nest visibility 99
- animal's use of marginal habitat 8

Agent of disruption

- oil field operations 7, 108
- hunting 8
- approach by human 116
- harassment 37, 101
- recreation 96, 99
- motor boats 3, 99
- general human activity 10, 24, 35

Highly sensitive situations

- nesting birds 3, 96, 101
- calving/postcalving 10
- areas near "gallinaceous guzzlers" 108

Specific effect

- decreased survival of young 10, 35, 37, 101
- inhibition of reproductive functions 24, 37
- reduced hatching success 7, 96, 99
- abortion/fetus damage 35, 37
- egg loss 3, 101
- decrease in young per female 8, 116
- nest abandonment 108

5. **Interference with Movement**

Species affected

- caribou 10
- deer 61
- red deer/chamois 8
- bears 74
- wolf 74
- gulls 74

Significance

- loss of young 10
- reduced reproductive success 8
- poor physical condition 8
- inadequate nutrition 74
- delay/failure to den 74

Agent of disruption

- hunting 8
- harassment 10
- general development activity 10
- wildlife feeding by oil field workers 74
- mining 61

Highly sensitive situations

- calving migration 10

Specific effect

- delayed arrival at calving grounds 10
- delay/failure to reach winter range 8, 61, 74

6. **Direct Mortality**

Species affected

- furbearers 42, 74
- ravens, gulls 42, 74

Agent of disruption

- wildlife feeding by oil field workers 42, 74
- improper handling/disposal of food and garbage 42, 74
- workers feeding animals along road 74

Specific effect

destruction of "nuisance" animals 42, 74
vehicle collisions 74
poaching 74

7. **Interference with Courtship**

Species affected

elk 58, 63, 88
caribou 23
upland birds 107, 108

Agent of disruption

approach by humans 88
seismic operations 58
oil field construction 107, 108
general human activity 23, 63

Specific effect

temporary disruption of breeding group activity 58, 63, 88
interference with timing/mating stimuli 23
abandonment of courtship grounds 107
disturbance of courting males 108

8. **Alteration of Behavior**

Species affected

bears 38, 39, 42, 45, 84, 91
wolf 74
fox 29, 74

Significance

destruction of "nuisance" animals 74
human injury/property damage 74, 91

Agent of disruption

wildlife feeding 42, 74, 91
improper food/garbage storage 42, 74, 91
human/bear encounters 39, 91

Specific effect

loss of fear of humans - all references

9. **Neutral/Positive Effect**

Species affected

elk 58, 88, 111
moose 70
deer 11, 26, 30, 73
bighorn sheep 48, 114
brown/grizzly bears 44, 100
wolf 19
arctic fox 29
waterbirds 7, 13, 120
common loon 99
oldsquaw 120
herons 101
upland birds 73
bald eagle 80, 94
small mammals 73

Agent of disruption

oil field operations 7, 29, 44, 58, 120
recreation 13, 48, 88, 99, 114
construction 73, 111
presence/approach by humans 19, 70, 80, 94
harassment 88, 101
snowmobile 11, 26, 30

Aspect

wildlife numbers 7, 44, 48, 73, 80, 114, 120
reproductive success 99, 101, 120
nest density 80, 120
distribution 44, 58, 88
reaction to humans 13, 19, 29, 70, 94, 99, 100, 120
movements 11, 26, 30, 48, 58
use of traditional areas - all references except 11, 70, 94, 99, 101, 120

Traffic and Access-Related Activities

These activities are considered separately from other cases of human intrusion as some effects are unique to roads and rights-of-way, and a considerable amount of literature addresses this particular subject.

1. **Interrupted Activity/Flight**

Species affected

caribou 51, 100
elk 88, 90, 111, 113
pronghorn 12
moose 100
Dall sheep 100
wolf 100
fox 100
hare, porcupine 100

Significance

change in activity patterns 12, 100
inefficient use of habitat 100

Highly sensitive situations

young calves 100
male fox 100
winter range 12

Factors influencing magnitude of effect

vehicle stopping 88, 100, 111, 113
people leaving vehicle 88, 100, 111, 113
animal group size 100
sex 51
distance 90
daylight 88
cover 51
noise 100

2. **Avoidance/Displacement**

Species affected

elk 40, 47, 67, 68, 79, 82, 83, 85, 86, 88, 111, 118, 121
caribou 16, 57, 100
deer 83, 85, 86
brown bear 100
wolf 100
hare, porcupine 100

Agent of disruption

interstate 111, 113
park road 88, 100
forest road 68
primary/secondary road 47, 82, 83, 118
Alaska Pipeline haul road 57
oil field access road 121

Significance

decreased use of areas near road - all species references
change in distribution 16, 67, 79, 100
change in activity patterns 40, 79, 88, 100
inefficient use/use of marginal habitat 68, 79, 82, 118
alteration of movements 57
den displacement 100
change in group composition 16

Factors influencing magnitude of effect

road density 47, 82, 85, 100, 111, 118
intensity of road use 47, 82, 86, 87, 88, 100, 111, 118
type of road 47, 82, 83, 85
proximity to road 47, 68, 79
slope aspect 83
food/habitat availability 85, 86, 88, 100
openness of habitat 68, 79, 85, 86
presence of cover/screen 16, 67, 83, 111
season 16, 82
animal's previous experience with disruption 100
hunting 40, 47, 79

Highly sensitive situations

road crossing traditional use area 47, 79, 83
winter range 79, 85, 86
open areas 16, 68, 79, 83
construction of new roads 67, 82
female/young 16, 57, 118
hunted population 47

3. **Reduction in Available Habitat**

Species affected
elk 83, 118
reindeer 54
brown/grizzly bear 31, 87
shorebirds 100

Highly sensitive situations
high use wildlife areas 83
river bottoms 87

Significance
decrease in nest density 110
reduction in wildlife numbers 31, 87

Factors influencing magnitude of effect
traffic volume 110
road density 31
presence of cover 31, 83
slope aspect 83
presence of railroad 54

4. **Interference with Movement**

Species affected
elk 47, 111, 113
reindeer 54
caribou 100
mountain goat 90
Dall sheep 100
pronghorn 12
wolf 100
fox 100

Agent of disruption
interstate 111, 113
park road 90, 100
primary/secondary road 12, 47, 54
railroad 54

Factors influencing magnitude of effect
snow depth 12, 47
intensity of activity 12, 47, 90, 100
herd size 90, 100
migration 100
time of day 90
direction of travel 90
sex, age of leader 90
presence of cover 90

Specific effect
delay/barrier 54, 90, 100, 111, 113
use of access corridors as travel lanes 47, 100

5. **Direct Mortality**

Species affected
big game 95
elk 32, 47, 90
reindeer 54
mountain goat 90
furbearers 57
grizzly bear 87
raptors 32, 106
hare 100
general 57, 106, 109

Specific effect
poaching 32, 57, 87, 90, 95, 106
increased hunter access 32, 47, 90, 95, 106
vehicle collision 54, 90, 100, 106, 109

Highly sensitive situations
road close to migration routes/winter range 90
wildlife habituated to activity 54, 57, 90
open terrain 57
raptors using utility pole perches 32
winter 54

6. **Neutral/Positive Effects**

Species affected
elk 83, 88, 90, 111, 112, 113
caribou 100
reindeer 54
deer 18, 83
Dall sheep 100
moose 100
wolf 100
fox 39, 100
oystercatcher 110

Aspect
use of traditional areas 29, 83, 88, 100, 110, 111, 112
behavioral reaction to traffic 29, 54, 88, 90, 100, 111, 113
wildlife numbers 18
activity 112
nest density 110
raising of young 29

Presence of Human-Associated Structures and Facilities

This section addresses the effects of the physical presence of man-made structures (pipelines, powerlines, fences, roads, rights-of-way) existing in the absence of immediate human activity. It is assumed that an animal's response to a structure may be influenced, to some unknown degree, by its previous association with human activity.

1. **Avoidance/Displacement**

Species affected
general 32
caribou 49
wolf 71

Agent of disruption
right-of-way 32
pipeline 49
objects with recent human scent 71

Significance
interference with movement 49

2. **Interference with Movement**

Species affected
large mammals 55
elk 113
pronghorn 12
caribou 6, 23, 43, 49, 75, 78, 100

Significance
delay/failure to reach traditional range 6, 23, 75, 78, 100
reduced calf survival 75, 78
easier travel 6, 100
increased vulnerability to predators 6
interference with mating synchrony 23
disruption of social structure 23, 75
inefficient habitat use/abandonment of traditional areas 55, 75, 100

Agent of disruption
pipeline 43, 49, 75
road 100
fence/corral 12, 78, 113
rights-of-way/seismic trails 6
general physical barriers 23, 75

Factors influencing magnitude of effect
age/sex composition of group 43, 49
size of group 100
animal's previous experience with disruption 43
degree of insect harassment 43, 49
timing 49, 100
height of berm 43

Specific effect
delay/barrier - all references except 6
use of corridor as travel lane 6, 100
diversion of movement direction 6, 43, 49, 75, 100

Highly sensitive situations

female/young 23, 43, 75, 78, 113
pregnant female 6, 75, 78
breeding groups 23
calving/postcalving areas 75

3. **Direct Mortality**

Species affected

waterfowl 21, 32, 106, 117
cranes 32, 97
eagles 117
general 32, 117

Specific effect

collisions with utility lines - all references
oil field sumps 106

Highly sensitive situations

poor visibility conditions 97, 117

4. **Neutral/Positive Effects**

Species affected

general 42, 102
caribou 6, 43, 49, 78, 100
Dall sheep 100
elk 32, 111, 113
deer 32
wolf 71
arctic fox 29
raptors 93

Aspect

additional food, perch, nest sites 32, 42, 93
use of area near road/right-of-way 32, 42, 100
reaction to man-made structures 29, 32, 71, 102
winter use of seismic trails 6
use of pipeline crossing facilities 49
road crossing 100, 111
berm crossing 43
movement 78, 113
density 93
corridor crossing 32

Factors influencing magnitude of effect

height of berm 43
degree of noise/movement 102
fresh human scent 71
animal's previous experience with disruption 43, 49
age/sex composition of group 49
degree of insect harassment 43, 49
timing 49

Disturbance of Vegetation or Land Surface

1. **Reduction in Available Habitat**

Species affected

general 42, 92, 102, 106
big game 61
elk 82
deer 69, 73
bighorn sheep 119
brown bears 31
small mammals 73
upland birds 73

Highly sensitive situations

winter range 69, 92, 119
breeding areas 42, 92

Agent of disruption

road 31, 73, 82
mining 61
oil field operations 42, 106
livestock 119
subdivision 69
general development 92
summer cabins 31

Significance

decrease in aquatic productivity/food availability 102, 106
reduction in wildlife numbers 31, 69, 92, 119
decreased reproductive potential 42, 69
disease 119
decreased lamb survival 119
elimination of nest sites 42

2. **Change in Community Structure**

Species affected

deer 73
birds 4, 5, 73, 120
small mammals 73

Factors influencing magnitude of effect

width of corridor 5

Agent of disruption

transmission line corridor 4, 5
drilling 120
road/right-of-way 73

Specific effect

change in species composition 4, 5, 73, 120
change in species diversity 4, 5

Introduction of Harmful Substances into the Environment

1. **Reduction in Available Habitat**

Species affected

general 42, 53, 108
birds 42

Agent of disruption

natural gas leak 108
fuel, crude oil, mud spill 42
"dust shadow" from vehicle activity on gravel 42
brine spill 53

Specific effect

destruction/alteration of vegetation 42, 53, 108
loss of nesting habitat 42

2. **Direct Mortality**

Species affected

general 42, 106, 107
waterfowl 20, 52, 107
livestock 52

Agent of disruption

toxic amounts of hydrogen sulfide gas 106, 107
oil field storage pits (evaporation, sludge, etc.) 20, 52, 107
water pollution 42

APPENDIX B: ANNOTATED BIBLIOGRAPHY

1. Altmann, M. The flight distance in free-ranging big game. Journal of Wildlife Management. 22(2): 207-209; 1958.

The author concluded that numerous factors can influence the flight distance (distance to which a person can approach a wild animal without causing it to flee) of moose and elk, including reproductive and nutritional status; habitat; individual variation based on previous experience of animal. Long flight distances were observed during hunting season, for moose cows with calves, when author approached animal silently and under cover, and for single animals or those on the periphery of a group. Short flight distances were observed during rut, during winter, when animal approached by noisy tourists in area frequented by tourists, and for animals in a close group. In areas of rare human presence, elk were not wary. A longer flight distance was associated with the presence of vegetative cover.

2. Ames, D. R. Physiological responses to auditory stimuli. In: Fletcher, J. L.; Busnel, R. G., eds. Effects of noise on wildlife. New York: Academic Press; 1978: 23-45.

Experiments with lambs exposed to various sounds for 12 days found sound to be a stressor (any stimulus which provokes a response similar to those attributable to increased levels of ACTH or adrenocorticotropin, a hormone, released as a result of stress). Lambs appeared to show differentiation in response to sound level, intensity, and duration. Exposure to 75 dB and 100 dB sound caused significant changes in heart rate and breathing. Evidence of acclimation to sounds less than 100 dB was shown.

3. Ames, P. L.; Mersereau, G. S. Some factors in the decline of the osprey in Connecticut. Auk. 81(2): 173-185; 1964.

Reports incidence of ground-nesting osprey destroying eggs when flushing in response to rapid approach by speed boats. Birds apparently attempt to escape discovery by remaining on the nest as long as possible, then flushing directly from the incubation position, which increases the chance of eggs being crushed or pushed from the nest.

4. Anderson, S. H. Changes in forest bird species composition caused by transmission-line corridor cuts. American Birds. 33(1): 3-6; 1979.

Bird surveys before and after construction of a 150-ft wide transmission line in eastern deciduous forest showed (1) an increase in species composition and number of species, (2) a significant decrease in species diversity, (3) a decrease in the number of migrant and canopy-foraging species, and (4) an increase in species associated with grassland and edge (unstable) habitats.

5. Anderson, S. H.; Mann, K.; Shugart, H. H., Jr. The effect of transmission-line corridors on bird populations. American Midland Naturalist. 97(1): 216-221; 1977.

Observations of bird populations along four widths—40, 100, 200, 300 ft—of transmission line corridors in eastern deciduous forest showed that the 100-ft corridor had highest bird density and diversity, and seemed to increase the "edge effect" to the greatest degree. Narrower corridors showed the least change from a forest-bird community. Wide corridors tended to support grassland communities of birds not characteristic of the surrounding forest. The greatest species diversity was associated with forest habitat. Conversion of forest to corridor tended to selectively displace permanent resident species.

6. Banfield, A. W. F. The relationship of caribou migration behavior to pipeline construction. In: Geist, V.; Walther, F., eds. The behavior of ungulates and its relation to management. I.U.C.N. Publication New Series No. 24. Morges, Switzerland: International Union for Conservation of Nature and Natural Resources; 1971: 797-804.

Studies indicate that caribou tend to choose travel routes offering easiest walking condition. Migrating caribou on winter range have been observed to follow seismic lines for some distance, eventually turning off if the line departs from their normal route. Potential hazards of this practice include (1) increased vulnerability to wolves, (2) delay or failure to reach traditional calving grounds by pregnant females following lines too far, and (3) diversion of migration from normal route. These hazards are also associated with buried gas pipeline corridors.

Author suggests that most caribou herds are habituated to planes, but not helicopters, flying at heights of at least 1,000 ft. New jet-copters appear especially disturbing and often cause animals to change their direction of travel.

7. Barry, T. W.; Spencer, R. Wildlife response to oil well drilling. Progress Note No. 67. Ottawa, ON: Canadian Wildlife Service; 1976. 15 p.

The effects of oil drilling in the Mackenzie River delta were studied during one summer. Within 1.5 mi of the drilling rig, 43 percent of bird species were significantly less numerous than normal, 52 percent were unaffected, 5 percent were more abundant (ravens, whimbrels using area traditionally for nesting). No generalizations were possible as great variations in effect were indicated. Some species showed signs of habituation. Geese and swans, when molting or with downy young, moved or stayed at least 1.5 mi from the rig. White-fronted geese moved out of both rig and control (5mi away) areas. Hatching success was greater in the control area than the rig area.

Low-flying helicopters appeared to be the most disturbing factor, directly affecting a circle of at least 1.5 mi radius. Increased predation was observed on nests from which birds were disturbed. Disturbance decreased with increasing flight altitudes.

8. Batcheler, C. L. Compensatory response of artificially controlled mammal populations. Proceedings: New Zealand Ecological Society. 15: 25-30; 1968.

Analysis of data on red deer and chamois controlled by hunting indicates that favorable response to reduction in numbers (e.g., improved physical condition, increased reproduction) may be suppressed "when the control technique disrupts the ability of survivors to exploit preferred . . . habitat." Animals responded to increasing hunting pressure by using nonpreferred, marginal habitat and remaining on summer range during winter. Consequently, animals were in poorer condition and the young:female ratio decreased.

9. Behrand, D. F.; Lubeck, R. A. Summer flight behavior of white-tailed deer in two Adirondack forests. Journal of Wildlife Management. 32(3): 615-618; 1968.

Comparisons of summer flight behavior of white-tailed deer on hunted and unhunted areas support the hypothesis that response to people is greatly modified by experience. The flight distance for antlered deer on the hunted area was significantly greater than for antlerless deer on both areas.

10. Berger, T. R. The Berger report: northern frontier, northern homeland. Living Wilderness. 41(137): 4-33; 1977.

Snow geese staging for migration are highly sensitive to human presence, noise, and aircraft. Researchers have found that geese would not feed closer than 1.5 mi from a device simulating compressor station noise. Birds flying over it diverted their course by 90° or more. Geese flushed in response to aircraft flying at considerable distances (2 mi) and heights (8,000-10,000 ft). Deliberate harassment cleared flocks from a 5- by 10-mile area in 15 minutes.

Caribou are very sensitive during calving and postcalving periods. Disturbance preventing or delaying arrival at calving grounds can force calving in unsuitable areas and increase loss of young. The greatest loss of calves occurs in the postcalving aggregation when caribou are stressed by insects, nursing, and antler growth. Repeated disturbance by unfamiliar sights or noises may force caribou from their traditional range.

11. Bollinger, J. G.; Rongstad, O. J.; Soom, A.; Eckstein, R. G. Snowmobile noise effects on wildlife, 1972-1973 report. Madison, WI: University of Wisconsin, Engineering Experiment Station; 1973. 85 p. (Cited in Bury, R. L. Impact of snowmobiles on wildlife. Transactions of the North American Wildlife and Natural Resources Conference. 43: 149-156; 1978. Original not seen.)

This study found no increase in deer movements or change in activity patterns in response to snowmobiles. Deer seemed to react more to the sight than the noise of snowmobiles. Deer were observed to remain close to persons working with chain saws, but move away when a person tried to walk near them. Some disturbance was possible as snowmobiles initially moved into an area.

12. Bruns, E. H. Winter behavior of pronghorns in relation to habitat. Journal of Wildlife Management. 41(3): 560-571; 1977.

This study found that roads and fences were important in determining pronghorn use of winter range in Alberta. Four-strand barbed wire fences presented a major obstacle to pronghorn. The herd was generally within 0.3 mi of a highway, but tended to avoid crossing, probably due to traffic and snow in ditches. Pronghorn demonstrated low levels of daily activity, with breaks in the foraging-resting pattern caused by the approach of vehicles or predators.

13. Burger, J. The effect of human activity on birds at a coastal bay. Biological Conservation. 21(3): 231-241; 1981.

This research concerned the effects of various human activities on nonbreeding waterbirds in the New York City refuge near Kennedy Airport. Data showed that birds were present at a site more often in the absence than the presence of people. Responses to human activities varied according to the location and species of bird and the nature of the activity. Birds generally flushed in response to rapid and/or close movement. Herons, egrets, and shorebirds were most easily disturbed, often flying to distant marshes. Birds on water flushed least often; those on the beach most often. Birds generally did not respond to subsonic jets. They always flushed in response to the SST passing overhead, but often returned to their original position. The author believes that the presence of gulls near airports does not necessarily prove that the birds are undisturbed by noise. The airport may be the safest—or only—foraging/loafing area.

14. Busnel, R. G. Introduction. In: Fletcher, J. L.; Busnel, R. G., eds. Effects of noise on wildlife. New York: Academic Press; 1978: 7-22.

The author states that "wildlife reactions to noise are difficult to define or predict." Reactions vary considerably between and within species, depending on the biological state of the animal, the season, population density, physical parameters of the noise, and so on. Distinction must be made between permanent noise sources and intermittent and mobile sources. Transient loud noises generally provoke alarm. An animal's first reaction to a new noise is fear and avoidance. Many animals apparently learn to ignore noise that is not associated with negative experiences, for example, being chased. The negative association of a sound with humans may provoke avoidance. An unusual noise in combination with a visual stimulus (aircraft) may be particularly disturbing. It is difficult to determine if a response is due to noise alone.

15. Calef, G. W.; DeBock, E. A.; Lortie, G. M. The reaction of barren-ground caribou to aircraft. Arctic. 29(4): 201-212; 1976.

During spring and fall migration, the percentage of panic responses (animals out of control) and strong escape responses (trotting or running, continuing after aircraft passed) was high at aircraft altitudes of less than 200 ft, and decreased with increasing altitude. Only mild responses were observed at altitudes above 500 ft. On calving grounds and during early winter cold, a high percentage of panic and strong escape responses was observed at all altitudes up to 500 ft, with little decrease in response with increasing altitude. In contrast with other studies, fixed-wing aircraft provoked a greater response than helicopters. Following caribou with a helicopter once they started moving caused extreme panic. Cows did not abandon calves in five cases of low overhead passes or helicopters landing nearby. Calves appeared more reactive than other caribou during spring and fall. Cows with calves appeared no more sensitive than other caribou during fall. Caribou at river crossings were more reactive. Group size, terrain, and vegetation type had no significant effect on response. The authors discuss contrasting results obtained by other researchers. An altitude of 1,000 ft is suggested for aircraft to avoid provoking injurious responses.

16. Cameron, R. D.; Whitten, K. R.; Smith, W. T.; Roby, P. D. Caribou distribution and group composition associated with construction of the Trans-Alaska pipeline. Canadian Field-Naturalist. 93(2): 155-162; 1979.

This study evaluated the seasonality of caribou response to pipeline and construction activity. Regional comparisons of survey data show corridor-related abnormalities in caribou distribution and group composition. Avoidance of the Prudhoe Bay area, traditionally a part of the herd's calving grounds, was noted throughout the study, though use of adjacent regions continued. Changes near Prudhoe Bay reflect the pattern of disturbance-related abandonment of range, which is thought to be a gradual process occurring with increasing avoidance of adverse stimuli. Summer avoidance of the haul road corridor was primarily by cows with calves. Greater visibility on the flat coastal plain may influence the degree of avoidance because of the importance of visual stimuli to caribou. Prudhoe Bay avoidance continued during fall; but cow/calf avoidance of the corridor decreased.

17. Campbell, B.; Remington, R. Influence of construction activities on water-use patterns of desert bighorn sheep. Wildlife Society Bulletin. 9(1): 63-65; 1981.

Watering activities of desert bighorn sheep changed significantly after construction was begun near a traditional water source. Under undisturbed conditions, peak watering activity occurred between 6 a.m. and 8 a.m. To avoid human disturbance, bighorn visited water (1) during the short period between dawn and start of work, and (2) after the work day. No visits occurred between 6 a.m. and 2 p.m. while construction was in progress. Such a shift results in inefficient energy use and, potentially, lower reproductive output. Normal activity patterns allow minimum energy to be expended in obtaining water by visiting during the coolest parts of the day. Habitat near the water source may be overutilized if sheep use the area for bedding to avoid night travel.

18. Carbaugh, B.; Vaughan, J. P.; Bellis, E. D.; Graves, H. B. Distribution and activity of white-tailed deer along an interstate highway. Journal of Wildlife Management. 39(3): 570-581; 1975.

This study analyzed white-tailed deer distribution and activity along forested and agricultural sections of an interstate. The impact of the highway on deer abundance and distribution and the relationship between deer activity and vehicle collisions were found to be functions of the highway location relative to deer requisites (feeding and resting sites) and to availability of feeding areas other than the right-of-way. No relationship was observed between traffic volume and numbers of deer seen.

19. Chapman, R. C. Human disturbance at wolf dens - a management problem. In: Linn, R. M., ed. Proceedings, first conference on scientific research in the National Parks; 1976 November 9-12; New Orleans, LA. Vol. 1. Transactions and Proceedings Series No. 5. Washington, DC: U.S. Department of the Interior, National Park Service; 1979: 323-328.

Wolf response to humans near pups was highly variable, ranging from no response to flight, temporary abandonment of pups, or movement of pups from the den. Pup mortality was not reported. Disturbance of den areas prior to whelping may influence den selection. Response to disturbance appears dependent on the number and social position of wolves at the home site, the wolves' previous experience with humans, and severity of the disturbance. Wolves were generally not disturbed by humans further than 0.5 mi in open areas and 0.25 mi in forested areas. Wolves regularly den within 1.5 mi of established human activity centers in the park. The author considers this a "safe" distance for exclusion of human activity in open areas. Smaller areas may be adequate in forested areas. Wolves that are more shy of humans may require larger closed areas.

20. Childress, J. The impacts of energy development on Colorado's wildlife. Proceedings Western Association Fish and Wildlife Agencies. 51: 196-201; 1978.

Passage of a federal law requiring covering of oil pits has reduced loss of waterfowl to these ponds.

21. Cornwell, G.; Hochbaum, H. A. Collisions with wires - a source of anatid mortality. Wilson Bulletin. 83(3): 305-306; 1971.

Observations on northern prairie breeding grounds suggest that duck collisions with overhead wires are common, though generally unnoticed and unreported. Transmission lines can become a frequent local source of duck mortality. The authors suggest that alternatives to running overhead lines through marshes be considered.

22. Cottereau, P. Effect of sonic boom from aircraft on wildlife and animal husbandry. In: Fletcher, J. L.; Busnel, R. G., eds., Effects of noise on wildlife. New York: Academic Press; 1978: 63-79.

General conclusions from a number of studies indicate that farm animals and wild animals are typically startled by the first exposure to a sonic boom. The reaction is usually slight, with little effect on behavior, and most animals appear to adapt to further booms. More studies are needed on the direct effects of booms on wild animals. Sonic booms are more disturbing to birds than to mammals, and may adversely affect colonial nesters.

23. Dauphine, T. C., Jr.; McClure, R. L. Synchronous mating in Canadian barren-ground caribou. Journal of Wildlife Management. 38(1): 54-66; 1974.

Evidence indicates that synchronous conceptions are essential to successful reproduction in barren-ground caribou. Dates of mating are influenced by environmental and social factors that may be disturbed by increased levels of human activity. Migration may serve an important function in synchronous breeding. Disturbance during autumn migration may interfere with communication of mating stimuli. Physical barriers on migration routes could alter the timing and synchrony of mating by (1) confining the population to a portion of their range, causing greater variation in prerutting conditions among females, and (2) forcing migration through unfamiliar areas, which may alter the social composition of rutting bands.

24. DeForge, J. R. Stress: is it limiting bighorn? In: Desert Bighorn Council. Transactions-1976; 1976 April 7-9; Bahia Kino, Mexico. Las Vegas, NV: Desert Bighorn Council. 20: 30-31; 1976.

Bighorn sheep are very sensitive to human intrusion and may be driven from portions of their home range.

The species' social organization is such that, if habitat is lost, sheep congregate in an adjacent area, causing local overpopulation and increased stress. This triggers a behavioral-physiological self-regulatory mechanism evolved to control population growth. Sheep then experience behavioral disturbances, inhibition of reproductive functions, and decreased resistance to disease, leading ultimately to a population reduction.

25. deVos, A. Behavior of barren-ground caribou on their calving grounds. Journal of Wildlife Management. 24(3): 250-258; 1960.

The author observed the reactions of caribou to his approach. Herds generally stampeded in tight formation in response to a close approach, but ran in more loosely formed groups when less alarmed. Large bands were more easily approached. Cows with calves appeared very sensitive and often continued to flee after the rest of the herd had settled.

26. Dorrance, M. J.; Savage, P. J.; Huff, D. E. Effects of snowmobiles on white-tailed deer. Journal of Wildlife Management. 39(3): 563-569; 1975.

Data suggest that deer, which had not been hunted for several years, became habituated to snowmobiles in an area receiving heavy, weekend recreational snowmobile use. Light traffic displaced deer from areas immediately adjacent to trails. Increased traffic thereafter caused no further response. In an area where snowmobiles were generally prohibited, deer home-range size, movements, and distance to nearest trails increased with snowmobile activity.

27. Dunaway, D. J. Bighorn sheep habitat management in the Inyo National Forest—a new approach. In: Desert Bighorn Council. Transactions-1971; 1971 April 7-9; Santa Fe, NM. Las Vegas, NV: Desert Bighorn Council; 15: 18-23; 1971a.

The author suggests that the increase in human use of bighorn sheep ranges may be the major factor contributing to the decline in bighorn numbers. Though no statistically sound data are available, the relationship of presently occupied bighorn ranges to human use in the Sierra Nevada offers supporting evidence. In areas where a large increase in human use has had the greatest impact, two of five sheep ranges described in 1948 appear unoccupied; one contains half of the 1948 population. Where human use has remained low (two areas), sheep populations are static.

28. Dunaway, D. J. Human disturbance as a limiting factor of Sierra Nevada bighorn sheep. In: Transactions of the first North American wild sheep conference; 1971 April 14-15; Fort Collins, CO. Fort Collins, CO: Colorado State University, Department of Fishery and Wildlife Biology; 1971b: 165-173.

Although difficult to prove, it appears that human disturbance may be a major factor that limits the bighorn in the Sierra." Normal limiting factors would probably not be effective in depressing a population which has decreased significantly since 1950. A threefold increase in recreational use is the only major difference in the ranges, which were previously rarely visited. The relationship between heavy human use and absence of bighorn is stressed. The author warns that continued losses may lead to eventual extinction.

29. Eberhardt, L. E.; Hanson, W. C.; Bengtson, J. L.; Garrott, R. A.; Hanson, E. E. Arctic fox home range characteristics in an oil-development area. Journal of Wildlife Management. 46(1): 183-190; 1982.

Petroleum development facilities were present in the home ranges of all radio-tracked foxes (14). Avoidance of sites with high levels of human activity varied among foxes. Resident foxes successfully raised young in natural dens within 83 ft of heavily traveled roads, and 165 ft of operating drill rigs. Foraging was common at sites where garbage and handouts were available, in years of lemming abundance as well as scarcity. Juvenile use of developed sites increased as young became more mobile in late summer. Garbage food sources may have contributed to changes in the Prudhoe Bay fox population, which was more dense and experienced less dramatic cyclic fluctuations than populations in less disturbed areas. No differences in natural habitat qualities were apparent between areas. Little or no commercial trapping occurred on the study area.

30. Eckstein, R. G.; O'Brien, T. F.; Rongstad, O. J.; Bollinger, J. G. Snowmobile effects on movements of white-tailed deer: a case study. Environmental Conservation. 6(1): 45-51; 1979.

Data showed that snowmobile activity had no significant effect on home-range size, habitat use, or daily activity patterns of white-tailed deer wintering in Wisconsin. Snowmobile activity did cause some deer to leave the immediate vicinity of the snowmobile trail. Darkness decreased the reaction to disturbance. Deer appeared to react more to a person walking than on snowmobile.

31. Elgmork, K. Human impact on a brown bear population (*Ursus arctos* L.). Biological Conservation. 13(2): 81-103; 1978.

This study looked at the effect of human activity on a remnant brown bear population in southern Norway over 25 years. Bear reports were compared with indices of human activity, primarily the building of a forest road network and clearcutting. Forest road density was used as an indicator of human impact. The number of bear observations was negatively correlated with forest road density and positively correlated with length of timberline in an area. Negative tendencies were also indicated in areas close to cabin concentrations. The author feels this effect may be more visible later, as extensive building of cabins has occurred only in the last 10 years. A theoretical model is developed—and supported by field observations—relating bear observations, timberline, and roads.

32. Ellis, D. H.; Goodwin, J. G., Jr.; Hunt, J. R. Wildlife and electric power transmission. In: Fletcher, J. L.; Busnel, R. G., eds. Effects of noise on wildlife. New York: Academic Press; 1978: 81-104.

The potential effects of powerlines and rights-of-way are described. Construction and maintenance activities may cause displacement of wildlife. Wildlife avoidance of powerline corridors has been little studied. No published studies are known on the response of wilderness species to powerlines. Collisions with wires have been documented for many species of birds. These generally involve few birds, but can be serious mortality factors in some cases. Legal and illegal hunting increases wildlife mortality along rights-of-way and transmission line access roads, especially in previously unroaded areas. Raptors perched on utility poles are particularly vulnerable. Studies indicate that hunters concentrate along roads and cleared trails, and this has been shown to affect elk movement. Benefits of powerlines include increased food for big game along corridors and additional perches and nest sites for raptors. Research in Idaho and Montana showed that a transmission line did not make a right-of-way less attractive to deer and elk feeding in the cleared area during early spring. No significant difference in big game use of rights-of-way and control clearings was noted. Elk and deer showed no apparent hesitation in crossing the corridor.

33. Epsmark, Y. Behavior reactions of reindeer exposed to sonic booms. Journal of the British Deer Society. 2(8): 800-802; 1972.

Reindeer held in an enclosure showed moderate reactions (startle response, raising head, pricking ears) when exposed to 36 sonic booms. Panic response and extensive changes in behavior were not observed. No difference in reaction to varied boom strengths was observed. This may be explained by possible habituation, or differences in individual sensitivities. Sleeping and grazing animals appeared less startled. Effects on reproduction were not part of this study. Therefore, negative influences of sonic booms on reproduction cannot be excluded, as sensitivity may increase during this period.

34. Faro, J. B.; Eide, S. H. Management of McNeil River State Game Sanctuary for nonconsumptive use of Alaskan brown bears. Proceedings of the Western Association of State Game and Fish Commissioners. 54: 113-118; 1974.

An increase in numbers of visitors attempting to photograph bear concentrations at waterfalls on the McNeil River caused bear-human conflicts. Activity patterns and tolerance of bears changed in response to increasing human disturbance. Bears left the falls as people arrived, gradually returned as people settled, and left again as visitors departed. Heaviest use by bears occurred in the evening in the absence of humans. With light disturbance, bears tended to use the falls all day. Evidence of abandonment of the area by bears is indicated. In previous years, bears had appeared quite tolerant of infrequent human activity. As visitor numbers increased, bears entered camps more often and showed tolerance only if human activities remained within previously established patterns.

35. Geist, V. A behavioural approach to the management of wild ungulates. In: Duffey, E.; Watt, A. S., eds. The scientific management of animal and plant communities for conservation: eleventh symposium British Ecological Society. Oxford: Blackwell Scientific Publications; 1970: 413-424.

General effects of human disturbance on ungulates are described. Voluntary abandonment of available habitat, in response to disturbance, will confine a population to a smaller, often less favorable, area. This may result in detrimental physiological effects on the animals and wasted habitat. The severity of the effect depends on such factors as the social behavior of a species. Disturbance may upset the animals' energy budgets, ultimately resulting in decreased reproductive performance caused by absorption of embryos, lower birth weights, and reduced survival of young. The paper also discusses behavioral aspects of disturbance.

36. Geist, V. Bighorn sheep biology. The Wildlife Society News. 136: 61; 1971a.

"Mammals learn to minimize encounters with humans, if harassed enough, by reducing activity to areas, habitats, and times of day where encounters with humans are minimal." This can change the ecology or reduce the size of a population by habituating animals to live in "second-rate" habitats (reference 8 is cited as an example).

37. Geist, V. Is big game harassment harmful? Oilweek. 22(17): 12-13; 1971b.

Harassment of caribou is most detrimental at critical times such as late pregnancy, calving, and during very cold weather. Chasing pregnant females for long distances (by aircraft or vehicle) can cause abortion or fetus displacement. Excitement upsets the animal's hormonal system, and may adversely affect embryo growth. Severe weight loss in early gestation, which may result from harassment combined with natural stress, has been documented to cause fetus resorption in female reindeer. Disturbance of caribou at calving time can potentially result in trampling, desertion, or increased predation of young.

38. Geist, V. Behavior. In: Schmidt, J. L.; Gilbert, D. L., eds. Big game of North America: ecology and management. Harrisburg, PA: Stackpole Books; 1978: 283-296.

The principles of learning explain many responses of wildlife to human disturbance. Animals may initially react with fright to an unusual sound, but subsequent behavior depends on the experiences associated with the sound. Animals often learn to ignore persistent, localized noise (airports, industrial activity) that they can approach or avoid. They will respond with excitation and flight to sounds associated with alarming events (pursuit by vehicle) but may search for the source of sounds with positive associations (chain saw noise indicating food to deer).

Avoidance or abandonment of areas associated with unpleasant experiences, such as human disturbance, may result in a reduction in range. Predation, increased energy expenditure, and loss of access to resources may subsequently reduce the population. Highly gregarious ungulates are generally most seriously affected.

If human contacts continue to occur and are not negatively reinforced, grizzly bears will not only learn to ignore people, but will proceed to the next stage of behavior—total exploration—which must be preceded by attack.

39. Graber, D.; White, M. Management of black bears and humans in Yosemite National Park. Cal-Neva Wildlife. 1978: 42-51.

A recent increase in bear/human conflicts in Yosemite backcountry can most likely be explained by the great influx of hikers and campers during the past decade. This has increased familiarity and, subsequently, reduced fear of humans by bears whose home-ranges include backcountry camping areas.

40. Gruell, G. E.; Becker, K.; Roby, G.; Johnson, R. Gros Ventre Cooperative Elk Study - progress report. Jackson, WY: U.S. Department of Agriculture, Forest Service, Bridger-Teton National Forest and Wyoming Game and Fish Department; 1975. 127 p.

This study on the influence of logging on elk concluded that the activity, not the physical existence, of primitive roads influences elk behavior. Data indicate that four-wheel-drive roads had minimum influence on elk when used infrequently during summer. During hunting season, elk avoided areas of regularly used roads. Their movements increased and became more erratic, apparently influenced by hunter disturbance and, possibly, rutting activities.

41. Gunn, A.; Miller, F. L. Responses of Peary caribou cow-calf pairs to helicopter harassment in the Canadian high arctic. In: Reimers, E.; Gaare, E.; Skjennelberg, S., eds. Proceedings, second international reindeer/caribou symposium; 1979 September 17-21; Roros, Norway. Trondheim, Norway: Direktoratet for viltog Jerskvannsfisk; 1980: 497-507.

Cow-calf responses to helicopter passes of 790 to 1,220 ft were observed. Calves tended to be more alert, respond sooner, and initiate cow-calf regrouping more often than their maternal cows. The level of response was less in August than in July. Responses diminished as the helicopter departed. The tendency of cow-calf pairs to reunite increased the response level of other caribou. The behavior of the maternal cow apparently acted as a signal for the group to move away from the disturbance.

42. Hanley, P. T.; Hemming, J. E.; Morsell, J. W.; Morehouse, T. A.; Leask, L. E.; Harrison, G. S. Natural resource protection and petroleum development in Alaska. Report prepared for Office of Biological Services, Fish and Wildlife Service, U.S. Department of the Interior, Washington, DC. 318 p.

General impacts of petroleum development in Alaska are described. Noise may cause animals to avoid areas while activity is in progress. Land surface alteration has eliminated critical habitat, particularly nest sites of shorebirds, which have been displaced in large numbers with adverse effects on their reproductive potential. Shorebird nesting densities have been reduced as a result of the "road effect"—a combination of noise, activity, and dust ("dust shadow") that extends the area of disturbance and habitat alteration beyond the actual road. Use of cleared areas (roads, rights-of-way, etc.) may increase for some species due to the presence of preferred food, increased edge, and easier travel routes. Improper garbage handling and feeding by workers have attracted bears and other scavengers, which have subsequently shown signs of behavior alteration, including loss of fear of humans. Fuel, oil, and mud spills reduce habitat by destroying vegetation. Fuel spills are especially destructive. Water pollution is more serious than land pollution and may cause injury or death of wildlife.

43. Hanson, W. C. Caribou encounters with pipelines in northern Alaska. Canadian Field-Naturalist. 95(1): 57-62; 1981.

Caribou reactions to raised berms resulting from pipeline burial were observed. Caribou movements were deflected when berms were higher than 1.2 m; but the animals readily crossed lower berms. Bulls showed greater acceptance of the berms than did cows and calves, especially during the second study season. Caribou sensitivity to the installation appeared to decrease with increased experience. Animals often seemed reluctant to leave elevated berms when a breeze offered relief from insect harassment.

44. Harding, L.; Nagy, J. A. Responses of grizzly bears to hydrocarbon exploration on Richards Island, Northwest Territories, Canada. In: Martinka, C. J.; McArthur, K. L., eds. Bears - their biology and management. [Calgary, AB]: The Bear Biology Association; 1980: 227-280.

Observations showed that although bears coexisted with industrial activity they appeared to actively avoid drilling and staging camps. Bears entering camps fled quickly from crowds and motorized vehicles. Some bears wintered successfully in dens 1 to 4 mi from active camps. Others abandoned dens directly disturbed by seismic vehicle and gravel mining activities. Bear responses to aircraft were variable and unpredictable. Most animals responded with some degree of aversion and/or energy expenditure. Bears responded more to helicopters than to fixed-wing aircraft. Animals previously captured and tranquilized avoided subsequent aircraft approaches. Although there is no evidence to suggest that current numbers and distribution—which have apparently stabilized in relation to existing facilities—of bears are significantly affected by oil field activities, the authors feel that cumulative impacts of proposed development will reduce the current population to the point where its continued existence will depend on immigration.

45. Harms, D. R. Black bear management in Yosemite National Park. In: Martinka, C. J.; McArthur, K. L., eds. Bears - their biology and management. [Calgary, AB]: The Bear Biology Association; 1980: 203-212.

"The natural behavior, foraging habits, distribution, and numbers of black bears in Yosemite National Park have been significantly altered by habituation to human-supplied food sources." Extensive development, and high levels and patterns of visitor use, have concentrated human use in available bear habitat, increasing the potential for bear/human encounters. Repeated food-reward associations with people, in addition to a loss of fear of humans, have contributed to the bears developing increasingly sophisticated depredation patterns.

46. Harrison, R. T. Quantifying the acoustic dose when determining the effects of noise on wildlife. In: Fletcher, J. L.; Busnel, R. G., eds. Effects of noise on wildlife. New York: Academic Press; 1978: 267-285.

We have little knowledge of the threshold levels at which particular sounds are perceived by wildlife species, or how animals specifically react to a particular sound. Mere perception of certain sounds by wildlife can cause significant reactions. Often it is the information carried by the perception of the sound rather than the sound itself that causes the reaction.

Carnivores, such as grizzly bears, are a concern in areas affected by petroleum activities, and this review focuses on them.

47. Hershey, T. J.; Leege, T. A. Influences of logging on elk on summer range in northcentral Idaho. In: Hieb, S. R., ed. Proceedings, elk-logging-roads symposium. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station; 1976: 78-82.

Data showed that elk avoided habitat within 0.25 mi and showed preference for areas more than 0.25 mi from primary and secondary roads. Use apparently decreased in proportion to road density, intensity, type, and use season. A long-established road open to traffic and crossing an elk use area disrupted elk within 0.25 mi by forcing them to disperse farther from the road, or causing their elimination through increased hunter access and harvest. The population studied was heavily hunted and vulnerable due to road densities and clearcuts. When undisturbed, elk began to use roads as travel lanes and areas close to roads for feeding and resting when snow depth was more than 12 inches. Elk were closest to roads in November.

48. Hicks, L. L.; Elder, J. M. Human disturbance of Sierra Nevada bighorn sheep. Journal of Wildlife Management. 43(4): 909-915; 1979.

Recreational use has apparently not decreased Mount Baxter California bighorn numbers. Overall bighorn distribution was not negatively related to human presence, and was positively related to food resources. Foot trails did not adversely affect sheep movement and were often used by the animals. Humans and bighorn were generally spatially separated on summer range due to preferences for different habitat features. Frequent contact was limited to specific areas, where sheep appear conditioned to hikers and can watch them approach from some distance below. Herd size and the distance and elevation of a person in relation to the sheep influence the sheep's reaction to human approach. Bighorn reacted more often to an approach from above than one from below. Smaller groups appeared more susceptible to disturbance. Results of this study were based on low human use (under 25 per day).

49. Hinman, R. The impact of oil development on wildlife populations in northern Alaska. Proceedings, Annual Conference of Western Association of State Game and Fish Commissioners. 54: 156-164; 1974.

A study by Child (1973) on pipeline crossing by caribou found that the majority of caribou tended to avoid simulated pipeline structures. Less than 25 percent used ramps and underpasses; the rest did not cross. The degree to which crossing facilities were used depended to some extent on the age and sex composition of the group, the degree of insect harassment, and chronology. There was some evidence that caribou might habituate to the structure with experience.

50. Hood, R. E.; Inglis, J. M. Behavioral responses of white-tailed deer to intensive ranching operations. Journal of Wildlife Management. 38(3): 488-498; 1974.

Data suggested that deer home ranges were enlarged and/or completely shifted in response to repeated cattle roundup disturbance. After initiation of roundups, all deer made frequent excursions outside their known home ranges, often independent of the timing or intensity of disturbance. Deer reaction to cattle drives varied by sex. Bucks responded more than does, generally reacting with a long flight, and ranging farther during disturbance than at other times. Does usually took a circuitous escape route, but returned within a few hours, and did not range farther during disturbance than at other times.

51. Horejsi, B. L. Behavioral response of barren-ground caribou to a moving vehicle. Arctic. 34(2): 180-185; 1981.

"In general, caribou exhibit signs of anxiety and fear when encountering a fast-moving vehicle, and they exert themselves strenuously for a short period when withdrawing from a vehicle. It appears that caribou react to a vehicle based on the rate of approach, involving the principle of looming, rather than on the movement itself." Looming is "the accelerated magnification of the form of an approaching object." Most caribou reacted to a pickup, traveling at least 35 mi/h, by running (48 percent) or trotting (38 percent) away. Response differed by sex in forested habitat, where males allowed a much closer approach than females, but not in open habitat.

52. Interstate Oil Compact Commission. Additional environmental problems relating to oil and gas production. Oklahoma City, OK; 1974. 16 p.

In response to a survey, nine States reported wildlife deaths due to pits associated with oil field operations. Significant numbers of animals were involved in California and Colorado. The problem was continuing in three States, and of short duration or unique in the others. Five States reported specific instances of waterfowl deaths on reserve pits, especially during migration. The main causes of death included: (1) coating of birds with oil from the pit, preventing flight, and (2) ingestion of toxic substances as a result of drinking in the pits. Livestock drownings have also been reported.

53. Kennedy, K. The environmental impacts of energy extraction. Environmental Views. 2(1): 3-8; 1979.

Salt water spills, generally from injection pipelines, are relatively unpublicized, but "definitely on the rise, in contrast to the declining volume of oil spilled." Water associated with oil wells typically contains a very high concentration of salt which, when mixed with surface fresh water, can make it undrinkable. On land, the salts can kill plants.

54. Klein, D. R. Reaction of reindeer to obstructions and disturbances. Science. 173: 393-398; 1971.

Well-traveled highways and railroads have obstructed movements of wild reindeer in Scandinavia and caused them to abandon a portion of their range. Reindeer stopped crossing railroad tracks, which transected their range, when train traffic increased several years after construction of the tracks. The animals have apparently become somewhat habituated to normal amounts of highway traffic. However, vehicle collisions kill many animals each year, especially in winter, when reindeer use roads and railroads as snow-free travel routes. Evidence suggests that reindeer (wild and domesticated) in poor physical condition are less able to adjust to environmental disruptions than animals in good physical condition. The author believes that "the Scandinavian experiences with reindeer should provide a basis for anticipating the problems to be encountered with caribou."

55. Klein, D. R. The impact of oil development in the northern environment. Petrolieri d'Italia. 1972 October: 39-44.

Obstruction of seasonal migrations of large mammals reduces efficiency of habitat utilization, and may isolate essential range components, causing a reduction in animal numbers. Wildlife displaced as a result of human disturbance cannot be expected to find suitable, unoccupied habitat to support them in adjacent areas, but will potentially die of natural causes or displace other animals. We must assume that a balance already exists between the habitat and resident animals in areas adjacent to disturbance.

The Rocky Mountain area, including bighorn sheep range, has received considerable emphasis in wildlife-petroleum research, especially in recent years.

56. Klein, D. R. The reaction of some northern mammals to aircraft disturbance. In: Eleventh International Congress of Game Biologists; 1973 September 3-7; Stockholm, Sweden. Stockholm, Sweden: National Swedish Environmental Protection Board; 1974: 377-383.

Caribou generally showed stronger and/or more frequent reactions: (1) to helicopters than fixed-wing aircraft at low altitudes; (2) when aircraft altitude was 200 ft or less (strong flight and panic responses); (3) during summer rather than spring migration, except during periods of severe insect harassment, when reactions decreased; and (4) in larger groups (more than 10), especially cow-calf-yearling groups. Caribou often changed their activity or altered their behavior in response to aircraft. Moose showed greater indifference to aircraft, though cows and calves often ran. Wolves appeared least disturbed and showed evidence of habituation. Grizzly bears reacted very strongly, running and attempting to avoid the aircraft. The previous experience of wildlife with aircraft may be an important consideration in Alaskan and Canadian studies.

57. Klein, D. R. The Alaska oil pipeline in retrospect. Transactions of the North American Wildlife and Natural Resources Conference. 44: 235-246; 1979.

Caribou have not adjusted as well as moose to the presence of the trans-Alaska pipeline. Research has shown that caribou have altered their movements and patterns of range use in relation to the pipeline corridor. Cows with calves show pronounced avoidance of the pipeline, road, and oil field. Traffic and human activity appear more directly responsible for avoidance behavior than does the physical presence of the pipeline, road, and facilities. Animals along the haul road are especially vulnerable to poaching because of the open terrain and the fact that many became tame during the peak of construction activity. Poaching, especially of furbearers, has increased as pipeline-related traffic has decreased.

58. Knight, J. E. Effect of hydrocarbon development on elk movements and distribution in northern Michigan. Ann Arbor, MI: University of Michigan; 1980. 79 p. Ph.D. dissertation.

Seismic activity significantly affected movements, but not distribution and range use, of elk. Distances moved were generally inverse to the distance from seismic activity, and represented an increase of 2 to 3.5 times normal daily movement. The movement response occurred immediately following the disturbance, and normal activity patterns were followed the day after. Bulls generally did not move as far as cows when disturbed. Data suggest that, as a result, harems may be broken up and herd organization disrupted during rut. Cows with calves moved significantly farther than cows without calves. Oil well activity did not affect movements or distribution of elk. Until elk become accustomed to noise and activity at drilling rigs, which extend the influence of drilling beyond the actual site, they may avoid parts of their range. On the other hand, noise allows animals to become aware of disturbance before it is seen, so they are not startled.

59. Kovach, S. D. An ecological survey of the White Mountain Peak bighorn. In: Desert Bighorn Council. Transactions-1979; 1979 April 4-6; Boulder City, NV. Las Vegas, NV: Desert Bighorn Council; 23: 57-61; 1979.

Observations suggested that bighorn sheep would not tolerate a direct approach, or approach from above, by humans. The critical flight distance observed for active approach to bighorns, at which they immediately left the area, appeared to be 300 to 350 ft. The animals were apparently not disturbed by people in vehicles, but fled if a person left the vehicle.

60. Kushlan, J. A. Effects of helicopters on wading bird colonies. Journal of Wildlife Management. 43(3): 756-760; 1979.

Neither fixed-wing aircraft nor helicopters flying at altitudes of at least 200 ft "drastically disturbed" egret and heron colonies. Ninety percent of the birds showed no reaction or merely looked up. Disturbance caused by helicopters was less than or equal to that caused by fixed-wing aircraft. The author cautions that the effects of aircraft surveys may differ under other conditions or with other aircraft.

61. Kvale, C. T. Preliminary phosphate mining impacts on mule deer, elk, and moose in southeastern Idaho. Proceedings, Western Association of Fish and Wildlife Agencies. 60: 527-545; 1980.

Phosphate mining activities apparently contributed to a delay in mule deer migration to winter range. Increasing snow accumulation may have added to the delay. Deer migrating through a mine site area (including roads, railroads, human activity) arrived significantly later on the winter range than those that bypassed the mine area. Forced delays in migration, with increasing snow accumulation, could cause sufficient additional stress to be detrimental to wildlife. Population dynamics may ultimately be affected. The author concludes that the number of acres removed from big game production will ultimately determine the impact of phosphate mining on ungulates.

62. Leslie, D. M., Jr.; Douglas, C. L. Human disturbance at water sources of desert bighorn sheep. Wildlife Society Bulletin. 8(4): 284-290; 1980.

Desert bighorn sheep altered their behavior and movements in response to construction activity near their primary watering hole. The percentage of sheep watering at the construction site declined significantly during construction and increased significantly at a less disturbed site. The sheep that continued to water near construction altered their direction of approach to avoid the impacted area yet maximize visual contact with the site. Assuming subpopulations at water sources are generally at summer carrying capacity, an increase in sheep numbers at one source would cause overutilization of forage. Sheep productivity was apparently not affected, but lamb survival may have been. The affected population was highly habituated to human presence. The authors conclude the observed responses would be magnified in areas where sheep were less accustomed to humans and where alternative water sources were not available.

63. Lieb, J. W.; Mossman, A. S. Final progress report on Roosevelt elk in Prairie Creek Redwoods State Park. 1967. Unpublished report submitted to California Department of Parks and Recreation, Sacramento, CA. 8 p.

Data indicate that human disturbance often caused elk to move from primary to secondary forage areas, and also disrupted rutting activities. Cows with young calves were observed to stay away from the central part of their home ranges, which received heavy human use, 3 to 6 weeks beyond normal.

64. Light, J. T. An ecological view of bighorn habitat on Mount San Antonio. In: Transactions of the first North American wild sheep conference; 1971 April 14-15; Fort Collins, CO. Fort Collins, CO: Colorado State University, Department of Fishery and Wildlife Biology; 1971: 150-157.

An analysis of bighorn sheep habitat features, habitat use, and human use indicates that heavy human use of high-value habitat is excluding bighorn use. There is evidence that large areas of bighorn habitat, suitable for occupancy, have been vacated by sheep as a result of human influence over a number of years. It appears that many documented cases of bighorn tolerance to humans occur mainly in areas where human use is relatively infrequent. Sheep may tolerate occasional human visitors, but continual human intrusion can cause stress and avoidance of disturbed areas. Observations suggest that ewes with lambs were most intolerant of humans, especially when the observer was in or above their cover element. Sheep rapidly retreated to cover when approached too closely in the open.

65. Luz, G. A.; Smith, J. B. Reactions of pronghorn antelope to helicopter overflight. Journal of the Acoustical Society of America. 59(6): 1514-1515; 1976.

Pronghorn showed no reaction to helicopter overflights of 400 ft altitude and 3,000 ft slant range. Muscle tensing and interruption of grazing were observed as the aircraft descended toward the herd. The animals ran when the helicopter was at an altitude of 150 ft and slant range of 500 ft. The pronghorn did not react to 60 dB noise, but reacted strongly to 70 dB. Helicopters are rare in the area studied. These results are in contrast to other observations of deer near a heliport apparently remaining undisturbed when a helicopter hovered 75 ft overhead.

66. Lynch, T. E.; Speake, D. W. Eastern wild turkey behavioral responses induced by sonic boom. In: Fletcher, J. L.; Busnel, R. G., eds. Effects of noise on wildlife. New York: Academic Press; 1978: 47-61.

Exposure of wild turkey brood groups and hens on nests to real and simulated sonic booms caused no apparent abnormal behavior that would reduce productivity. Alert responses lasting less than 30 seconds were generally observed.

67. Lyon, L. J. Coordinating forestry and elk management in Montana: initial recommendations. Transactions of the North American wildlife and natural resources conference. 40: 193-200; 1975.

Studies on elk (hunted population) on a Montana summer range concluded that elk moved away from logging and road construction activity until adequate security was achieved. Elk density decreased in a drainage where construction and logging occurred and increased over the ridgeline in adjacent, undisturbed drainages. Ridgeline road construction caused a reduction in density near the ridge, further movement, and changes in elk distribution for up to 4 mi. Elk reactions to even long-established, low-quality forest roads appeared to be generally negative unless adjacent timber cover was very dense. New road construction appeared to be extremely disruptive.

68. Lyon, L. J. Habitat effectiveness for elk as influenced by roads and cover. Journal of Forestry. 77(10): 658-660; 1979.

Data from 8 years of pellet counts show that western Montana elk tend to avoid habitat adjacent to open forest roads. Elk use increased with increasing distance from roads. The area avoided was inversely proportional to amount of tree cover. The author concludes that open forest roads decrease the effectiveness of available elk habitat.

69. Mackie, R. J.; Pac, D. F. Deer and subdivisions in the Bridger Mountains, Montana. Proceedings Western Association of Fish and Wildlife Agencies. 1980: 517-526.

Development of subdivisions on or adjacent to critical mule deer winter range has an important influence on deer occurrence and abundance in the Bridger Range. A reduction in the amount, quality, or availability to deer of winter range—as a result of direct habitat loss or disturbance—can be expected to decrease numbers of deer on the winter range and in areas used by those deer in summer and fall. Loss of some areas will concentrate deer in smaller areas and/or force them to use marginal habitat. Deer on adjacent, undisturbed winter ranges will probably be affected as well. Disturbance will place additional energy costs on the deer and will increase the energy deficit on which they typically exist during winter. As a result, survival and reproductive potential may be reduced the following year.

70. McMillan, J. F. Some observations on moose in Yellowstone Park. American Midland Naturalist. 52(2): 392-399; 1954.

Observations suggest that variation in moose response to human approach depends on the activity of the animal, its relation to cover, and the manner of approach. Moose appeared more tolerant of a slow, quiet approach than a fast, noisy one. Moose showed evidence of habituation to humans. Animals in relatively undisturbed areas were less tolerant of disturbance than those in areas frequented by tourists. Vehicle sounds did not seem to alarm moose in areas near roads and activity. Noise combined with movement appeared to frighten animals more than noise alone.

71. Mech, L. D. The wolves of Isle Royale. Fauna Series 7. Washington, DC: U.S. Department of the Interior, National Park Service; 1966. 210 p.

Wolves appeared conditioned to planes as low as 100 to 200 ft after several harmless encounters. Packs encountered less frequently showed more concern about the plane. Observations suggested wolves were afraid of humans. They were easily chased from a moose carcass and did not return for several hours. Wolves appeared afraid of objects with recent human scent but not of man-made structures with no recent scent.

72. Memphis State University. Effects of noise on wildlife and other animals. 1971. Unpublished report prepared for U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Washington, DC. 74 p.

Literature dealing directly with the effects of noise on wildlife is limited. Effects can be inferred from lab studies on domestic animals, incidental observations of wildlife response to noise, and information on communication and auditory ranges of different species. Suspected effects of noise on wildlife include (1) masking of signals that influence courtship, spacing, care of young, prey detection and escape, etc., and consequent interference with these life processes, and (2) direct effects on physiological and behavioral processes, including hearing loss and noise-induced stress responses. A lack of visible response by an animal does not necessarily imply adaptation or lack of effect.

73. Michael, E. D. Effects of highway construction on game animals. Proceedings Annual Conference of the Southeastern Association of Fish and Wildlife Agencies. 32: 48-52; 1978.

Populations of white-tailed deer, rabbit, ruffed grouse, gray squirrel, and turkey were apparently not affected by road construction (using heavy equipment and blasting). The amount of animal sign near the highway did not differ significantly from the amount 1 mi away for any species. For these species, habitat loss is restricted to the area occupied by pavement, berm, and right-of-way. The addition of right-of-way vegetation and creation of ecotonal areas will cause some wildlife species to increase, while others decrease.

74. Milke, G. Animal feeding: problems and solutions. Special Report No. 14. Anchorage, AK: Joint State/Federal Fish and Wildlife Advisory Team; 1977. 11 p.

Animal feeding was a major problem during construction of the Alaska pipeline and is continuing into the operations and maintenance phase to a lesser extent. Large numbers of animals—especially bears, wolves, foxes, ground squirrels, gulls, and ravens—were attracted to human activity as a result of active feeding by employees and improper handling and disposal of food and garbage. The actual and potential adverse effects of animal feeding include: (1) alteration of normal behavior and/or nutrition, which may be passed on to subsequent generations; (2) loss of fear of humans, which may lead to human injury or property damage; (3) destruction and/or harassment of "nuisance" animals; (4) vehicle collisions with, or illegal shooting of, animals waiting along road for "handouts" (commonly given by truckers); (5) delay of traditional movements by animals which stay near camps to be fed. These may interfere with normal denning of bears, and nutrition of wolves, which normally follow caribou.

75. Miller, F. L. A new era—are migratory barren-ground caribou and petroleum exploitation compatible? Transactions of the Northeastern Section, The Wildlife Society. 31: 45-55; 1974.

Results of intensive study indicate that the primary factor limiting growth of the Kaminuriak caribou population was a low rate of annual increment due to high losses of calves during the first month of life. The strong affinity of females for calving and postcalving areas increases the vulnerability of calves to human disturbance. Patterns of activity during and after calving may be necessary for maintaining the social structure and discreteness of the population. Pipeline construction near calving and summering areas may threaten socialization, causing abandonment of traditional ranges, greater calf mortality, and reduction of the population. The cow-calf bond may be weakened if arrival on the calving ground is delayed, or the energy cost of travel is raised, due to the presence of barriers on the migration route. Calf survival would most likely decrease because bonding minimizes the possibility of permanent cow-calf separation during the critical time following birth.

76. Miller, F. L.; Gunn, A. Responses of Peary caribou and muskoxen to helicopter harassment. Occasional Paper No. 40. Ottawa, ON: Canadian Wildlife Service; 1979. 90 p.

Responses of caribou and muskoxen to helicopter overflights simulating activities associated with construction of an arctic gas pipeline were intensively observed and analyzed. The results indicate that (1) "the responsiveness of cows and calves of both species and solitary bull muskoxen, (2) group size and type, (3) number of calves in a group, (4) the position of the sun and direction of the wind relative to the helicopter flight, (5) previous activity of the animals, and (6) the terrain" were factors contributing to the level of response. An inverse relationship was exhibited between response level and helicopter altitude or distance from helicopter landing. Cows and calves tended to be more responsive than other sex/age groups. Overt responses (movement in response to the stimulus, defense formations, alert response) were observed for 64 percent of the caribou samples and 44 percent of the muskox samples. Ground activities by people after landings seemed to influence subsequent responses more than did the presence of the helicopter. Circling overflights caused greater responses than other types of flights. Habituation was evident within, but not between, sets of passes simulating cargo-slinging. Visible pathological conditions, group splintering, and calf desertion were not observed. The energy costs of responses, and their consequences for the population, are not known.

77. Miller, F. L.; Gunn, A. Behavioral responses of muskox herds to simulation of cargo slinging by helicopter, Northwest Territories. Canadian Field-Naturalist. 94(1): 52-60; 1980.

The investigators observed muskox responses to sets of overflights of five to six passes each. During the second year of study, a trend toward decreasing responsiveness within sets of passes was evident, indicating short-term habituation. Muskoxen tended to canter, gallop, or form group defense formations more often during the first three passes. They remained bedded or foraging, walked away, or became alert more often during the last three passes of each set. One herd showed some evidence of long-term habituation; but two herds showed greater responsiveness with time, apparently due to rutting activity. The animals' previous experience, stability of the social order, and recent exposure to wolf attack may contribute to variations in response. There was no evidence of injury, herd splintering, or range abandonment.

78. Miller, F. L.; Jonkel, C. J.; Tessier, G. D. Group cohesion and leadership response by barren-ground caribou to man-made barriers. Arctic. 25(3): 193-202; 1972.

An attempt to corral migrating caribou with a man-made barrier failed because the animals would not leave the frozen water course at the corral entrance nor deviate from learned travel routes. Some caribou were delayed by attempts to circumvent the barrier. Others overcame it and continued on their course. Energy expenditures were increased for caribou forced to crawl under or jump over the fence. Any disruption of caribou movement could be detrimental to cow and calf survival.

79. Morgantini, L. E.; Hudson, R. J. Human disturbance and habitat selection in elk. In: Boyce, M. S.; Hayden-Wing, L. D., eds. North American elk: ecology, behavior and management. Laramie, WY: University of Wyoming; 1979: 132-139.

Data on wintering elk in Alberta indicate that elk habitat selection in winter may be determined by human activity and not simply a response to thermal environment. The habitat selected was not related to weather conditions, but was strongly related to time of day and proximity to roads. Daily activity patterns were influenced by roads. Extensive use and overgrazing of marginal sectors of potentially available grassland was evident in an area crossed by a road system. This use pattern may have been related to a special winter hunt resulting in heavy harvest for 6 years prior to the study. During the hunt, distribution and habitat use changed significantly. Elk abandoned the grassland and moved to open mountain slopes.

80. Newman, J. R.; Brennan, W. H.; Smith, L. M. Twelve-year changes in nesting patterns of bald eagles on San Juan Island, Wash. Murrelet. 58(2): 37-39; 1977.

Although human activity in areas near bald eagle nests has increased significantly since 1962-63, nest surveys show that numbers of nests and occupied nests have also increased significantly. Most nests are much closer to roads and buildings now than in 1963. Near the greatest concentration of buildings alternate nests are associated with occupied nests, representing a change in nesting pattern. No productivity data were obtained.

81. Owens, N. W. Responses of wintering brent geese to human disturbance. Wildfowl. 28: 5-14; 1977.

Disturbance reduced feeding time (3 to 5 percent) and increased time spent in flight for wintering brant geese (*Branta bernicla bernicla*). Brant were very sensitive to aircraft disturbance, especially any plane below 1,650 ft and up to 1 mi away; slow, noisy aircraft—helicopters—"caused widespread panic." The geese also reacted to large birds with a slow wingbeat. Brant showed little reaction to nearby loud, but regular, sounds (weapon testing) after the first weeks. They flushed in response to unexpected sounds—nearby gunshots. Geese usually left the area when severely disturbed by people on the ground; however, they showed evidence of partial habituation to humans. When disturbances occurred very frequently, the geese appeared to become more easily disturbed with each subsequent disturbance. The birds were more easily disturbed when feeding in unfamiliar areas or areas associated with danger (hunting). Availability of alternate feeding areas appeared to influence avoidance of disturbed areas and areas with poor visibility. The author concludes that "disturbance would be harmful if it consistently resulted in birds losing more energy (through extra flying and lost feeding time) than they were able to make up by food intake" during undisturbed periods.

Waterfowl, and the impacts of activities associated with petroleum exploration and development, have been studied in some depth, which is reflected in this review.

82. Pedersen, R. J. Management and impacts of roads in relation to elk populations. In: Ittner, R.; Potter, D. R.; Agee, J. K.; Anschell, S., eds. Recreational impact on wildlands: conference proceedings; 1979 October 27-29; Seattle, WA. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, and U.S. Department of the Interior, National Park Service; 1979: 169-173.

During road construction, elk use declined adjacent to the disturbed area for 4,950 ft. Elk moved 825 ft to 2.5 mi from logging and road construction. Main roads caused the greatest, and primitive roads the least, reduction in elk use within 0.5 mi. Road density, location, use intensity, class, and season of use—independently or in combination—may constitute significant disturbance factors affecting elk. Roads ". . . affect elk populations directly by removing elk habitat from production, and indirectly by inducing a disturbance factor . . . which displaces elk from habitat adjacent to roads." Recreational visits occur "almost spontaneously" with access development.

83. Perry, C.; Overly, R. Impact of roads on big game distribution in portions of the Blue Mountains of Washington. In: Hieb, S. R., ed. Proceedings, elk-logging-roads symposium. Moscow, ID: University of Idaho, Forestry, Wildlife and Range Experiment Station; 1976: 62-68.

All roads through meadows and open forests significantly reduced elk use of adjacent habitat, especially on west- and south-facing slopes from 0.12 to 0.5 mi away. Limited data suggest that roads had little influence on elk use of adjacent habitat in dense forest. Roads on east slopes caused only minimum disruption of use. It appears that areas used most intensively by elk sustained the most reduction in use due to roads. Main and secondary roads on west and south slopes caused a significant decrease in deer use of adjacent meadows for 0.12 to 0.5 mi. Otherwise, the influence of roads on deer was variable and not significant.

84. Richens, V. B.; Lavigne, G. R. Response of white-tailed deer to snowmobiles and snowmobile trails in Maine. Canadian Field-Naturalist. 92(4): 334-344; 1978.

White-tailed deer response to snowmobiles seemed dependent on the deer's apparent security. Animals in the open or in hardwood stands tended to run when approached by snowmobile. Deer in softwood stands, which provided more cover, showed a greater tendency to stay when approached. A significantly greater number of deer ran from a person walking than from a person on snowmobile.

85. Rost, G. R. Response of deer and elk to roads. Fort Collins, CO: Colorado State University; 1976. 51 p. M.S. thesis.

Refer to 86.

86. Rost, G. R.; Bailey, J. A. Distribution of mule deer and elk in relation to roads. Journal of Wildlife Management. 43(3): 634-641; 1979.

Data from fecal pellet counts indicate that deer and elk avoid roads, especially areas within 660 ft. Road avoidance was greater (1) east than west of the Continental Divide, (2) along more heavily traveled roads (trends only), (3) by deer compared to elk, (4) for deer in shrub habitat compared to pine and juniper, and (5) in the species' primary winter habitat. The greater avoidance on the east side may reflect a greater availability of habitat away from roads due to lower snow accumulation. Data suggest that ungulates "may utilize areas near roads when hunger is sufficient to overcome fear." "Deer west of the Divide avoided roads, at least on some sites, even though snow accumulation presumably restricted their available habitat." Factors affecting the reactions of ungulates to roads and road-associated disturbance may be very complex and may include the species involved, the age and type of road, traffic density, road-associated construction, distance from road, vegetative type, season, whether the population is hunted, and whether the road is located in an abundant or scarce habitat type. The effects of roads on individual welfare and herd productivity are not clear.

87. Schallenberger, A. Review of oil and gas exploitation impacts on grizzly bears. Bear Biology Association Conference Series. 3: 271-276; 1980.

Raptors, or birds of prey, are one of the species groups emphasized in the literature related to animal disturbance and in this review.

The author concludes that "available information indicates that impacts of oil and gas exploitation should be considered primarily detrimental for grizzly bears in northwestern Montana." Research has shown that grizzlies tend to react strongly to aircraft, especially helicopters. Marked animals previously captured by aircraft show the greatest reaction. Helicopter disturbance may cause den abandonment. Biologists suggest that road development has contributed to a decline in numbers of bears by accelerating habitat loss and increasing hunting and poaching pressure. Use of river valleys for transportation corridors, campsites, and other activities magnifies the effect of human presence ". . . by concentrating it in some of the most vulnerable and essential grizzly habitat." Bear-human conflicts may increase as a result of secondary developments such as recreation, logging, livestock grazing, and construction of subdivisions.

88. Schultz, R. D.; Bailey, J. A. Responses of national park elk to human activity. Journal of Wildlife Management. 42(1): 91-100; 1978.

This study found no statistical evidence that heavy tourist activity or planned disturbance affect elk distribution, courtship behavior, movement patterns, or use of areas near roads. Elk generally accepted human activity and have apparently adapted to present levels of human disturbance. The authors suggest this is a learned response of unhunted elk. There was evidence, though not statistically significant, that elk avoided roads in early winter when forage was plentiful. The animals were apparently not disturbed by passing cars, but generally fled if a car slowed and prepared to stop. Elk reacted more to an approaching person than an approaching car. Elk-watching from parking lots and roads did not seem to significantly affect the animals' movements. People leaving the road caused elk to flee and caused disorganization of harems.

89. Simpson, S. G.; Hogan, M. E.; Derksen, D. V. Activity budgets and disturbance of molting Pacific brant in arctic Alaska. n.d. Unpublished paper on file at: U.S. Fish and Wildlife Service, 1011 East Tudor, Anchorage, AK.

Molting brant geese responded to aircraft, gunshots, and approaches by caribou and fox. Brant spent 3 percent of the time observed in disrupted activity, responding to disturbance. Brant responses included entering a nearby lake (44 percent), moving to the shoreline (21 percent), or no movement (21 percent). Mean duration of response was 5 minutes. There was no significant difference between duration of response to fixed-wing aircraft and helicopter. The proportion of "no response" to planes was greater than that for helicopters. Caribou and arctic fox caused large flocks of geese to move to the lake or shoreline. Birds appeared to become more sensitive to successive disturbances when disturbances were closely spaced.

90. Singer, F. J. Behavior of mountain goats, elk, and other wildlife in relation to U.S. Highway 2, Glacier National Park. 1975. Report prepared for Federal Highway Administration and Glacier National Park, West Glacier, MT. 96 p.

Mountain goats using a mineral lick were exposed to human activity along a highway that traversed their travelway, at a park exhibit near the lick, and by a nearby railroad. Goats reacted with avoidance and/or flight to all close interactions with humans. Animals at the lick showed evidence of habituation to noise from visitors at the exhibit and noise from trains. They continued to react to the sound and presence of vehicles and to loud and/or sudden nearby disturbances. A high level of disturbance by traffic and visitors was indicated by the behavior of goats crossing the highway. They responded by hesitating, fleeing, altering their crossing route, and/or delaying the crossing attempt. Unsuccessful crossing attempts occurred when goats were leaving the lick (42 percent of total attempts) and were significantly associated with the presence of visitors or heavy traffic.

Large groups, especially led by females with young, were most successful. Successful crossings were also associated with a twilight pattern of crossing that developed in response to disturbance. Goats used conifer cover when disturbed. Several goat-vehicle collisions, and many near-collisions, were observed. In several cases, females were separated from their young—one maybe permanently—by passing vehicles. Elk highway crossings were mainly twilight and nocturnal. Their routes were through conifer stands. Wintering elk were habituated to the highway and were very susceptible to poaching. Elk flight reactions were significantly correlated with location, and were greatest within 328 ft of the highway and in the backcountry.

91. Singer, F. J.; Bratton, S. P. Black bear/human conflicts in the Great Smoky Mountains National Park. In: Martinka, C. J.; McArthur, K. L., eds. Bears - their biology and management. [Calgary, AB]: The Bear Biology Association; 1980: 137-139.

The occurrence of black bear damage incidents in the park was associated with the number of visitor-nights at the campsite. Between 1963 and 1975, backcountry camping increased 250 percent. After 1973, damage incidents became more common in backcountry than front country. Food storage was a contributing factor in many incidents of property damage. Between 1964 and 1976, 71 percent of bear-caused personal injuries occurred along park roads receiving the heaviest traffic. Thirty-two cases involved people feeding bears.

92. Smith, R. K. Guest editorial: energy and the environment: planning for coexistence. Overthrust News. Overthrust Industrial Association, Denver, CO; 1981; 3: 11.

Although wildlife may range over large areas during much of the year, most species congregate on small areas that are critical to survival at some time during their life cycle (breeding areas, big game winter range, sage grouse lek). If development destroys the critical area, the entire population may be eliminated. Planning development for minimal impact on critical areas should reduce the adverse effects on a population.

93. Stahlecker, D. W. Effect of a new transmission line on wintering prairie raptors. Condor. 80(4): 444-446; 1978.

Wintering prairie raptors were counted along a right-of-way in Colorado before and after construction of a transmission line. Although utility towers constituted 1.5 percent available perches, 81 percent of all perched raptors were seen on them. Raptor distribution changed significantly after transmission line construction, as bird density was greatest 0.25 mi from the right-of-way. No density difference was apparent before construction.

94. Stalmaster, M. V.; Newman, J. R. Behavioral responses of wintering bald eagles to human activity. Journal of Wildlife Management. 42(3): 506-513; 1978.

Bald eagle tolerance of disturbance was determined by analyzing eagle distribution in relation to human activity and by measuring flight distances of eagles from simulated human disturbance. Eagle distribution and daily activity patterns were changed in response to human presence. Eagles were displaced to areas of lower human activity, preventing effective use of all feeding sites and forcing more birds to use marginal habitat and a smaller area. Feeding birds were disturbed by the mere presence of humans and generally did not return to the site of disturbance for several hours. Sensitivity to disturbance increased with age. Flight distances for adults were significantly greater than for juveniles. Young birds seemed to react more to adult flight behavior than to the human intruder and may in this way become sensitized to human activity. Flight distances were shorter in heavy vegetation than in open areas. Eagles showed evidence of habituation to routine human activities and noise. They were most tolerant when the source of noise was concealed from view. Gunshots caused overt escape behavior. Nonroutine activity on the river channel was most disturbing.

95. Stuart, R. W. Surface mining and wildlife. North Dakota Outdoors. 37(5): 2-7; 1974.

"Game departments in the northern Great Plains have been aware of the fact that accelerated prospecting and development of new oil fields during the past two decades has had an adverse impact on big game populations in the area of activities." This has resulted primarily from the building of well-maintained roads into previously inaccessible areas, which has increased pressure from legal hunting and poaching by work crews.

96. Swenson, J. E. Factors affecting status and reproduction of ospreys in Yellowstone National Park. Journal of Wildlife Management. 43(3): 595-601; 1979.

Human presence was thought to be a major factor contributing to low reproductive success, primarily due to low egg hatchability, of osprey nests on Yellowstone Lake. Success and productivity of nests on the lake were significantly lower than those of nests along streams, which were less disturbed, and of nests beyond 0.6 mi from campsites on the lake. The reproductive success of nests was increased by closing backcountry campsites within 0.6 mi of active nests. Shoreline use had a greater adverse effect on reproduction than boating did. The author suggests that the critical disturbance probably occurred during incubation. Shoreline human use may have contributed also to a loss of nests, between 1924 and 1974, from heavily used areas of the lake shoreline.

97. Tacha, T. C.; Martin, D. C.; Endicott, C. G. Mortality of sandhill cranes associated with utility highlines in Texas. In: Proceedings 1978 crane workshop; 1978 December 6-8; Rockport, TX. Fort Collins, CO: Colorado State University; 1979: 175-176.

Fifty-two sandhill cranes were found dead or dying from collisions with high voltage transmission lines and telephone lines. The collisions occurred when the birds attempted to return to their roost while fog was present. Others have noted large numbers of cranes dying from apparent collisions with utility lines during blizzards and dust storms.

98. Thomson, B. R. Reindeer disturbance. Journal of the British Deer Society. 2(8): 882; 1972.

Two years of observations in Norway determined that half of all stimuli to which reindeer reacted with alarm were human caused (hikers, hunters, snowmobiles, aircraft). The reindeer progressed in response from alert to alarm to flight, depending on the strength of the stimulus and the season. The animals were most responsive during winter and calving. Human scent, moving objects, and strange and/or sudden noises were especially alarming. Reindeer showed signs of habituation after repeated exposure to alarming sounds, but not human scent. Disturbance from loud noise was intensified if the alarming object was visible. Aircraft were very disturbing to the reindeer, interrupting activity and causing flight and panic responses. Natural predators also caused alarm and flight behavior.

99. Titus, J. R.; VanDruff, L. W. Response of the common loon to recreational pressure in the Boundary Waters Canoe Area, northeastern Minnesota. Wildlife Monograph 79; 1981. 59 p.

Data indicate that heavy recreational use had little or no effect on overall loon productivity. In the last 25 years, the adult loon population has increased 35 percent, despite an 800 to 900 percent increase in recreational use. Undisturbed loon pairs, and those habituating to human presence, seem to compensate for the slight reduction in nesting and brood-rearing success of individual pairs in areas of high human impact. Hatching success was significantly greater on smaller (generally remote) lakes, on no-motor lakes, and for less visible nests. Loon pairs on smaller lakes (trends only), on no-motor lakes, and with few human contacts showed greater success in brood rearing. Breeding pairs on remote, isolated lakes generally responded to human intrusion with more activity and excitement than those on more heavily used lakes. The behavior of loons conditioned to human use drew less attention to the nest site, expended less energy, and generally resulted in greater reproductive success. Factors which generally increased the tendency to flush and flushing distance include human approach (1) within the bird's line of vision, (2) with exaggerated or erratic movements and/or noise, and (3) early in the incubation period.

100. Tracy, D. M. Reactions of wildlife to human activity along Mount McKinley Park road. Fairbanks, AK: University of Alaska; 1977. 260 p. M.S. thesis.

Reactions of caribou, moose, Dall sheep, brown bears, red foxes, hares, and porcupines to traffic (buses) and human activity were observed. Avoidance was found only for some bears and foxes, possibly large bands of migrating caribou, and a few sensitive individuals of other species. Adult male foxes were often easily disturbed. Many individual animals appeared habituated to human activity. Responses of individual bears and wolves were highly variable, and included habituation, flight, and displacement of wolves from a den close to the road. Observations indicated that wolves could successfully den near the road if not approached by humans. Bears in the backcountry were observed to run several miles in response to human scent. Disturbances interrupted activity, decreased feeding, and increased movements by caribou within 660 ft of the road. Consequently, some areas near the road may be removed from effective habitat. Singles and small bands of caribou frequently crossed the road but showed caution in doing so, even in the absence of vehicles. The road occasionally diverted the direction of movement of caribou which used it for travel. Large migrating herds moved parallel to the road without crossing it. Disturbances thwarted some road crossings by migrating sheep but did not cause large-scale range abandonment. Some sheep crossed even in the presence of vehicles and people. Female ungulates with young were most easily disturbed. Many animals were attracted to the road. Porcupines and hares fed on new vegetation by the road in early summer but ran away from buses. They were rarely seen as food became more available in other areas. All species showed 40 percent "no visible response" between 165 and 330 ft from the road. Few visible responses were exhibited beyond 1,300 ft. Loud noises or people out of vehicles increased response strength for most species. Stopping vehicles disturbed foxes and sheep.

101. Tremblay, J.; Ellison, L. N. Effects of human disturbance on breeding of black-crowned night-herons. Auk. 96(2): 364-369; 1979.

"Visits to black-crowned night-heron colonies just before or during laying provoked abandonment of newly constructed nests and either predation of eggs or abandonment of eggs followed by predation. Investigator disturbance caused mortality of young in some situations. Frequent disturbance also discouraged the settlement of late-nesting night-herons . . . .Clutch size and fledging success of successful early nests were the same in frequently and infrequently disturbed colonies."

102. U.S. Department of Agriculture, Forest Service. Oil and gas lease applications on the Los Padres National Forest - draft environmental assessment. Goleta, CA: U.S. Department of Agriculture, Forest Service, Los Padres National Forest; 1981. 332 p.

The two greatest factors influencing the degree of decline in use of foraging habitat may be extensive area use by human activity and the presence of large, noisy equipment. Individuals of even intolerant species occasionally show "curiosity" and tolerance when feeding near quiet, stationary equipment. Aquatic habitat may be altered by siltation, which hinders productivity and population growth of aquatic organisms, and consequently decreases food availability for some species of wildlife.

103. U.S. Department of the Interior, Bureau of Land Management. Alaska natural gas transportation system - final environmental impact statement. Washington, DC: U.S. Department of the Interior, Bureau of Land Management; 1976a. 825 p. (pp. 322-329).

Studies on the effects of gas compressor noise simulations on wildlife determined that caribou, Dall sheep, and snow geese abandoned, or reduced their use of, areas within varying distances of compressor station simulators. Degree of avoidance by caribou varied with season. All species also diverted movements to avoid the source of noise. Geese appeared especially sensitive. Geese forced to detour around compressor stations near staging areas may not be able to compensate for the increased energy expenditure and may consequently migrate with insufficient reserves. Studies on impacts of aircraft disturbance on wildlife determined the following: (1) Dall sheep reactions to aircraft were relatively severe, including panic running, temporary desertion and/or reduced use of traditional areas following activities involving aircraft and generator noise, and flight in response to aircraft at relatively high altitudes. (2) Caribou, moose, grizzly bears, wolves, raptors, and waterfowl showed variable degrees of flight, interruption of activity, and panic. Degree of response was influenced by aircraft altitude, distance, and type of flight (low circling); group size; activity of animals; sex; season; and terrain. (3) Muskoxen may have shifted their traditional summer range by 16 mi in response to heavy helicopter traffic. (4) Waterfowl, shorebirds, and bald eagles exhibited reduced nesting success and production of young, nest abandonment, and loss of eggs in response to aircraft disturbance, especially by helicopters. The addition of on-the-ground human disturbance may increase the severity of impacts. (5) Muskoxen and Canada geese near airfields appeared habituated to aircraft. Waterfowl may adapt to float planes. Wolves apparently adapt regularly to aircraft noise if not subjected to aerial hunting.

104. U.S. Department of the Interior, Bureau of Land Management. Alaska natural gas transportation system - final environmental impact statement - Canada. Washington, DC: U.S. Department of the Interior. Bureau of Land Management; 1976b. 825 p. (pp. 501, 504).

Studies found that Dall sheep interrupted activities in response to blasting 3.5 mi away, though their reactions decreased over time. Waterfowl with young avoided drilling rigs within a 2.66 mi radius. Data show that peregrine falcons deserted nests in response to construction activity. Falcons may accommodate to construction noise, except blasting, if it is not centered near the nest. Caribou can apparently tolerate winter blasting if they are not hunted.

105. U.S. Department of the Interior, Bureau of Land Management. Alaska natural gas transportation system - final environmental impact statement - overview. Washington, DC: U.S. Department of the Interior, Bureau of Land Management; 1976c. 249 p. (p. 154).

Snow geese are especially sensitive to aircraft disturbance. Geese staging for fall migration have been observed to flush up to 9 mi from low-flying aircraft. Resting geese were disturbed by aircraft at 10,000 ft. Repeated disturbance may limit energy storage necessary for migration.

106. U.S. Department of the Interior, Bureau of Land Management. Kemmerer Resource Area oil and gas leasing environmental assessment record. Rock Springs, WY: U.S. Department of the Interior, Bureau of Land Management, Rock Springs District; 1979. 191 p.

Large predators may be severely affected by development activities due to their secretive nature and tendency to avoid humans. Oil field operations may force them to leave areas of disturbance. If alternative habitat is unavailable, their population would eventually decline to a level that could be supported by the remaining available habitat. Better access into remote areas will result in a "cumulative and continual" increase in numbers of road kills, as well as a greater incidence of illegal shooting, especially of raptors. Surface disturbance of watersheds may create impacts that severely reduce aquatic life downstream. Accidents involving toxic amounts of hydrogen sulfide, though unlikely, could be lethal for wildlife, especially in low areas. Evaporation and mud pits are serious hazards for waterfowl that may land in them.

107. U.S. Department of the Interior, Bureau of Land Management. Final environmental assessment: oil and gas leasing in the Roswell District, B.L.M. Roswell, NM: U.S. Department of the Interior, Bureau of Land Management, Roswell District; 1981. 149 p.

Noise from oil field operations interferes with "booming" by male prairie chickens during courtship. Development activities on the booming grounds may force birds to abandon the area. Human intrusion often prevents pronghorn from occupying an area. This would be serious if it curtailed the use of areas in which pronghorn congregate at critical times, namely areas of dependable forb production. Hydrogen sulfide gas is known to cause wildlife mortalities, but the extent of the problem is unknown. Brine evaporation pits, containing concentrated salts and oil films, cause "thousands of wildlife deaths, particularly birds, annually" (pp. 4-19).

108. U.S. Department of the Interior, Bureau of Land Management, and U.S. Department of Energy, Energy Regulatory Commission. Rocky Mountain pipeline project - draft environmental impact statement. Washington, DC: U.S. Department of the Interior, Bureau of Land Management and U.S. Department of Energy, Federal Energy Regulatory Commission; 1981. 305 p.

The impacts of pipeline construction on Gambel's quail would be significant if construction occurred, during the dry period, within 2 mi of gallinaceous guzzlers in nesting habitat. Disturbance could cause nest abandonment and a consequent reduction in reproductive success. Human activity may interfere with sage grouse courtship if males on leks are disturbed. Slow leaking of natural gas from the pipeline would destroy all vegetation in the area of the leak; but no direct impact to wildlife is expected.

109. U.S. Geological Survey. An environmental evaluation of potential petroleum development on the National Petroleum Reserve in Alaska. Washington, DC: U.S. Department of the Interior, U.S. Geological Survey; 1979. 238 p.

Dust from construction and/or traffic on gravel roads during early spring may cause early snowmelt and early greening of roadside vegetation. Animals tend to be attracted to roadsides until other food becomes available, thereby increasing the chances of wildlife-vehicle collisions.

110. van der Zande, A. N.; ter Keurs, W. J.; van der Weijden, W. J. The impact of roads on the densities of four bird species in an open field habitat: evidence of a long distance effect. Biological Conservation. 18(4): 299-321; 1980.

Data were collected on densities of breeding lapwings, godwits, oystercatchers, and redshanks at increasing distances from roads in an open field area of the Netherlands. Data indicated a direct relationship between population densities and distance from the road, except for oystercatchers. Oystercatcher densities decreased with increasing distance from the road. Disturbance intensity—the total population density loss over the whole disturbance distance—varied from 30 to 65 percent of the potential maximum density. Disturbance appeared to increase with traffic volume.

111. Ward, A. L. Elk behavior in relation to multiple uses on the Medicine Bow National Forest. Proceedings Western Association of State Game and Fish Commissioners. 43: 125-141; 1973.

Four-strand barbed wire fences had little influence on elk movement, though cows and calves were temporarily separated in some cases. Data show that an interstate highway (I-80) acted as a definite barrier to elk movement. Elk preferred to stay 300 yd from I-80 traffic, and from moving vehicles on logging roads. Logging roads did not act as a barrier when no traffic was present. Elk were frequently seen within 100 yd of recreational traffic on improved forest roads, especially when screened by conifers. Elk spent little time feeding in noisy areas near I-80 (62 dB for cars, 70 dB for trucks), but did not react to the noise when feeding. They quit feeding in response to a stopped vehicle and moved to cover if people approached. Elk apparently preferred to stay at least 0.5 mi from people out of vehicles—recreationists, logging crews. During timber harvest operations, elk moved from the area near the activity but were less affected in areas farther from the harvest and separated from it by a stand of conifers. A construction crew working on I-80 for 2 months did not cause elk to leave their range.

112. Ward, A. L. Elk behavior in relation to timber harvest operations and traffic on the Medicine Bow range in southcentral Wyoming. In: Hiebs, S. R., ed. Proceedings, elk-logging-roads symposium. Moscow, ID: University of Idaho, Forestry, Wildlife and Range Experiment Station; 1976: 32—43.

Traffic on forest roads had little effect on elk activity, especially beyond 0.25 mi. Elk road crossings occurred most frequently where desirable feeding sites were near the road. Timber harvest operations had a definite effect on elk distribution. The impact was less severe in areas where harvest operations were separated by 1.5 mi and activity was concentrated within one clearcut at a time. Elk use, however, was excluded from approximately 25 mi^2 during high-intensity and widely scattered timber operations in open areas with greater visibility.

113. Ward, A. L.; Cupal, J. J.; Lea, A. L.; Oakley, C. A.; Weeks, R. W. Elk behavior in relation to cattle grazing, forest recreation, and traffic. Transactions of the North American Wildlife and Natural Resources Conference. 38: 327-337; 1973.

Refer to 111.

114. Wehausen, J. D.; Hicks, L. L.; Garber, D. P.; Elder, J. Bighorn sheep management in the Sierra Nevada. In: Desert Bighorn Council, Transactions-1977; [Dates of meeting unknown]; Las Cruces, NM. Las Vegas, NV: Desert Bighorn Council; 21: 30-31; 1977.

Sierra Nevada bighorn ewe-lamb groups were studied in relation to human activity to test Dunaway's hypothesis that human disturbance was causing the disappearance of herds. Research showed that bighorn activity patterns were clearly influenced—though not severely—by frequent encounters with hikers. No permanent spatial displacement was evident and the population was increasing. The sheep reacted most strongly to humans approaching from above. The authors discourage extrapolation of results to other situations, including that of substantially greater human use of the study area. They also question the correlations leading to Dunaway's hypothesis.

115. Werschkul, D. F.; McMahon, E.; Leitschuh, M. Some effects of human activities on the great blue heron in Oregon. Wilson Bulletin. 88(4): 660-662; 1976.

The mean size of great blue heron rookeries was greater in undisturbed areas than in areas within 0.3 mi from logging operations. Nest density and nest occupancy were significantly less in disturbed heronries than in undisturbed ones. The average distance from the nearest point of disturbance was greater for active than inactive nests. A shift in nesting activity away from the point of disturbance was observed in heronries near logging operations, but not in undisturbed heronries.

116. White, C. M.; Thurow, T.; Sullivan, J. F. Effects of controlled disturbance on ferruginous hawks as may occur during geothermal energy development. Geothermal Resources Council, Transactions. 3: 777-780; 1979.

Disturbance treatments consisted of frequent walking and driving to the nest and placing noisemakers near the nest. Hawk responses to disturbance were highly variable. Several nests were deserted and not reoccupied during the following year. Little nest failure was evident, but treatment nests fledged significantly fewer young than control nests. The author suggests a 1 mi buffer zone be established around each nest to minimize adverse impacts.

117. Willard, D. E. The impact of transmission lines on birds. In: Avery, M. L., ed. Impacts of transmission lines on birds in flight: proceedings of a workshop, Oak Ridge Associated Universities; 1978 January 31-February 2; Oak Ridge, TN. FWS/OBS 78/48. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service, Office of Biological Services; 1978: 3-7.

Collisions with transmission lines have been reported for approximately 280 species of birds. Collisions involving swans, pelicans, cranes, and eagles have been reported in greater numbers than their populations would suggest. Many kills apparently occur when large numbers of birds are surprised in conditions of poor visibility. Disturbance may be an important factor. Some species are more sensitive at specific places and times, such as during the breeding season. Collisions represent a small proportion of deaths nationwide, but may be significant locally and/or for species with small populations.

118. Witmer, G. W. Roosevelt elk habitat use in the Oregon coast range. Corvallis, OR: Oregon State University; 1982. 104 p. Ph.D. dissertation.

Habitat use data indicated that use of road areas by Roosevelt elk was inversely related to vehicular disturbance. Elk avoided roads, especially paved through roads. Cows exhibited the greatest avoidance response during calving and rut. Security needs appeared more important than weather in precluding movement of elk far into openings. Researchers have calculated that 23 to 50 percent of a section of land (640 acres), when bisected by a paved through road, would be forgone to elk. The author recommends closure of secondary roads.

119. Woodard, T. N.; Gutierrez, R. J.; Rutherford, W. H. Bighorn lamb production, survival, and mortality in southcentral Colorado. Journal of Wildlife Management. 38(4): 771-774; 1974.

Research determined that the bighorn sheep population under study was declining or stabilizing at a low number. Ewe-lamb ratios declined significantly between June and September. The approximate cause of lamb mortality and the consequent low population density was believed to be a pneumonia complex. The sheep were lambing at a high elevation where stress from early bad weather may have increased the lambs' susceptibility to disease. The ultimate cause of high lamb mortality was unknown but may have been related to a loss of historical winter range due to livestock operations. It has been shown that acquisition of critical winter range can increase lamb survival.

120. Wright, J. M.; Fancy, S. G. The response of birds and caribou to the 1980 drilling operation at the Point Thomson No. 4 well. 1980. Final report prepared for Exxon Co., U.S.A. by L.G.L. Ecological Research Associates, Inc. [place of publication unknown], 62 p.

Data on the responses of birds to an exploratory drilling operation on the Arctic coastal plain showed that bird species composition, community structure, abundance, and nest density were similar at the drilling and control sites. No consistent pattern of increased nesting failure was observed in areas close to disturbance. Elimination of 5 acres of one type of habitat did not eliminate nesting birds, but caused a change in species composition. Helicopters flushed many birds from nests, but did not cause a reduction in nest density. Oldsquaw ducks at the control site appeared more sensitive to disturbance than those at the drilling site. This may be evidence of habituation by the latter to constant nearby noise and activity or may have been related to the small size of the control group and/or the limited area of protected water available to them. Caribou were observed (1) in significantly fewer numbers, (2) for shorter periods of time, (3) moving at a faster rate, and (4) traveling more and feeding and resting less in the drilling area than in the control area. Caribou tended to avoid the area within 3,900 ft of the drilling site. Approach by personnel each time caribou entered the drilling site was considered the most important disturbance. Based on the results of other research, the authors believe that caribou will not continue to avoid the area when the sources of disturbance are removed (after one season).

121. Johnson, B. K.; Lockman, D. Response of elk during calving to oil/gas drilling activity in Snider Basin, Wyoming. Pittman-Robertson Job Completion Report #W27R. 1980. On file at: Wyoming Game and Fish Department, Big Piney, WY. 14 p.

Preliminary data show elk responded to drilling-associated activity by avoiding roads and the drill site. Elk use of the basin was greater after than during drilling operations. The animals moved away from the drill site and did not appear to adjust to its presence. Elk cows moved their calves away from access roads at an earlier age during the summer when drilling occurred. Elk exhibited the strongest response to activity on roads. Few conclusive data are available on the effect of the drilling rig on elk distribution and use of meadows.

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Bromley, Marianne. Wildlife management implications of petroleum exploration and development in wildland environments. General Technical Report INT-191. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station; 1985. 42 p.

This report describes: (1) petroleum exploration, development, and production; (2) potential environmental disruptions; (3) effects of disruptions on wildlife behavior, habitat, and populations; and (4) strategies for minimizing and mitigating adverse effects. The section on impacts includes a detailed outline/index referring to an annotated bibliography. Major wildlife groups discussed are ungulates, carnivores, waterfowl, raptors, songbirds, shorebirds, and furbearers. Fish and other aquatic organisms are not covered.

KEYWORDS: petroleum development, wildlife, impacts, disruption, mitigation, bibliography

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